INTER-REGIONAL INTERACTION AND URBANISM IN THE ANCIENT INDUS VALLEY: A GEOLOGIC PROVENIENCE STUDY OF HARAPPA’S ROCK AND MINERAL ASSEMBLAGE

by

Randall William Law II

A dissertation submitted in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

(Anthropology)

at the

UNIVERSITY OF WISCONSIN – MADISON

2008

A dissertation entitled

Inter-Regional Interaction & Urbanism
in the Ancient Indus Valley:
A Geologic Provenience Study of
Harappa's Rock and Mineral Assemblage

submitted to the Graduate School of the
University of Wisconsin-Madison
in partial fulfillment of the requirements for the
degree of Doctor of Philosophy

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Date of Final Oral Examination:

May 8, 2008

Month & Year Degree to be awarded: **December** **May** 2008 **August**

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Approval Signatures of Dissertation Committee

Signature, Dean of Graduate School

VOLUME ONE

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Abstract

This dissertation is an examination of inter-regional interaction and urbanism in the Greater Indus region of Pakistan and northwestern India during the period that encompassed the development, existence and decline of South Asia's first urbanized society, the Indus Civilization (ca. 2600 to 1900 BC). The principal research objective is to identify the geologic sources from which the stone and metal artifacts excavated at Harappa, a site that grew to become one of the largest Indus Civilization cities, were most likely derived. Using techniques ranging from studies of basic macroscopic and mineralogical attributes to highly precise and accurate isotopic and elemental assays, I compare grindingstone, chert, steatite, agate, vesuvianite-grossular, alabaster, limestone and various metal artifacts to samples of those materials collected from sources across South Asia. Geologic provenience determinations, periodized with reference to Harappa's detailed chronological sequence, are used to inform three lines of inquiry. The first two concern identifying the Harappans' inter-regional relationships, defining their extent and tracking them through time. The third involves elucidating synchronic variations in those relationships at the local or site level.

The results of this research indicate that, in the process of acquiring the rock and mineral resources, residents of Harappa interacted with peoples dwelling in most every

major region in and around the Indus Valley at one time or another. Among the most significant (i.e., the most extensive and enduring) of those inter-regional relationships were those with groups dwelling in highland regions north of the Indus Valley. During all chronological periods, some rocks and minerals were acquired from sources outside of the Greater Indus region, thus indicating that external trade was a continuous aspect of the socio-economic lives of the site's residents. Source utilization for some materials (chert, grindingstone) changed significantly over time while for others (steatite) it remained steady throughout the chronological sequence. Harappans dwelling in different parts of the city had access to and were using the same basic varieties of raw materials from the same geologic sources. Two important exceptions are vesuvianite-grossular and "Ernestite," which were mainly used by residents of mounds E and ET during Period 3C.

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Acknowledgements

I am indebted to numerous individuals for making this research project possible. However, I wish to first and foremost thank Dr. Jonathan Mark Kenoyer – my advisor, teacher, friend, guide and guru at the University of Wisconsin-Madison, at Harappa and across South Asia. Studying, excavating and traveling with him for the past decade has been a wonderful, life-enriching experience. Shukria ji.

Thanks also to the other members of my dissertation committee – Drs. T. Douglas Price, Jason Yaeger, Sissel Schroeder and Nick Cahill for agreeing to read this beast of a thesis several years after I first promised to deliver it. I am especially grateful to Dr. Price who, as the Director of the Laboratory for Archaeological Chemistry (LARCH) at the University of Wisconsin–Madison, generously provided access to the instrumentation on which a great deal of the data presented here was produced. I wish to both thank and blame Dr. James Burton – the associate-director of the LARCH. Every time I walked into his office or the lab I came away inspired and brimming with ideas for new studies that I had to undertake (was absolutely convinced were imperative) for this research project. It literally added years to the production this dissertation. And it was completely worth it.

Thanks to all of the Madison Indus-walas, especially my traveling companions in South Asia (Dr.) Brad Chase and Katie Lindstrom, as well as Brett Hoffman, Mary Davis, Gregg Jamison and Alison Carter, who I've sometimes cajoled into undertaking aspects of this project with me. Thanks also to the staff (past and present) at the Department of Anthropology – Maggie Brandenburg, Peg Erdman Jan Holmes and Tammy Schlender who kept my academic world at the University of Wisconsin spinning in greased grooves.

I am grateful to all the members of the Harappa Archaeological Research Project but most especially to the project directors Drs. Richard Meadow and J. Mark Kenoyer for inviting me to come to the site, teaching me to excavate there and allowing me to study the materials that they and others had labored many seasons to recover. Many thanks also to Dr. Rita Wright (for allowing me to examine the Beas Survey stone!), Dr. Sharri Clark, Dr. William Belcher, Dr. Rae Beaubian, Mr. Nadeem Ghouri (and his wonderful family in Lahore) and all of the camp staff, site workmen and various friends of the HARP.

I am deeply indebted to Dr. Fazal Dad Kakar, Director-General, Department of Archaeology and Museums Government of Pakistan, and the former DG, Saeed-ur-Rehman for allowing me to examine and analyze the materials from sites across Pakistan. Thanks as well to Saleem-ul-Haq, Afzal Khan, Shabaz Khan and Asim Dogar also of the Department of Archaeology and Museums, Government of Pakistan. Thanks also to Dr. Farzand Massih, former curator of the Harappa Museum and now at the Department of Archaeology, Punjab University. I am grateful to Drs. Asma Ibrahim and Kaleem Lashari for their support, friendship and very good advice as well.

Dr. Ihsan Ali – formerly at the Department of Archaeology, University of Peshawar and now Vice-Chancellor at Hazara University has helped me in countless ways beginning even before he was my 2000-2001 Fulbright Fellowship co-advisor in Pakistan. Thanks also to the other Archaeology faculty members at University of Peshawar – especially Farooq Swati, Taj Ali, Muktar Durrani, Gul Rahim Khan, Nidaullah Sehrai and Shah Nasir Khan, who made my stay in the NWFP extremely interesting and productive. The late Prof. Farzand Durrani was also a great source of inspiration while I was in Peshawar.

I am grateful to Dr. Nilofer Shaikh for her tremendous generosity during my visits to Shah Abdul Latif University, Khairpur and to the faculty there – especially Dr. Qasid Mallah (my Wisconsin class fellow), Gulam Mustafa Shar for helping me to obtain samples for this study and G.M. Vessar for guiding me through the Rohri Hills and Thar Desert.

Thanks to Dr. Javed Hussain and Professor Nargis Rashid for making me feel welcome at the General History Department, University of Karachi. With the help of former U of K students Sulaiman Ahmad, Sajid Hussain and Javaid Iqbal, I was able to undertake a highly productive field excursion through southern Sindh.

Many thanks to Farid Khan of the Bannu Archaeological Project for inviting to see the sites of that region and to search the riverbeds for chert. Thanks also to the other project members – Drs. Ken Thomas, Robert Knox, Cameron Petrie and Justin Morris.

During my 2000-2001 Fulbright and American Institute of Pakistan Studies (AIPS) funded research, I received outstanding support from then Executive-Director of the United States Educational Foundation in Pakistan Dr. Robert Lawrence as well as Nadeem Akbar and Ghulam Rasool at the AIPS's Islamabad Center. I also received much excellent advice from the AIPS's scholar-in-residence at that time, Dr. Michael Meister (University of Pennsylvania) as well as Dr. A.H. Dani, Quaid-i-Azam University, Islamabad.

I will be forever grateful to Azra and Peter Meadows of the University of Glasgow for inviting me to join them on their 2001 expedition along the Makran coast of Pakistan.

In India, I wish to thank R.S. Bisht, R.S. Fonia, K.C Nariyal, Amarendra Nath, Tejas Gardes, V.N. Prabhakar, Manoj Saxena, Navratna Pathak and Manoj Joshi of the Archaeological Survey of India (ASI), each of whom has helped me in innumerable ways.

Dr. Kuldeep Bhan of the Department of Archaeology, Maharaja Sayajirao University (MSU), Baroda provided several important samples for this study and he and his students – Kishore Ragubhans and Arun Malik (now both with the ASI), personally guided me through much of Rajasthan and Gujarat. S.P. Gupta and K.N. Dikshit at the Indian Archaeological Society in New Delhi made me feel most welcome during my visits there. I deeply regret that Gupta-ji did not live to see the completion of this dissertation.

In France, I wish to thank Jean-François Jarrige, Catherine Jarrige and Jérôme Haquet at Musée national des Arts asiatiques-Guimet, Paris. Their generosity in providing samples from Mehrgarh, Nausharo and Mundigak greatly enriched this dissertation.

Thanks to Professor Maurizio Tosi (Università di Bologna) and Dr. Massimo Vidale (Instituto italiano per l'africa el'oriente) for supplementing this study with artifacts from the site of Shahr-i-Sokhta in Iran and (from Vidale) several sites in Pakistan.

I thank my friends in the geological sciences for their tremendous help and genuine interest in this project. In Pakistan, I gratefully acknowledge the late Dr. Syed Hamidullah (see dedication) at the Centre of Excellence in Geology, University Peshawar as well as present and former members of the Centre such as Drs. Qasim Jan, Irshad Ahmed and Noor Jehan; Dr. Syed Baqri of the Pakistan Museum of Natural History, with whom I spent the single most productive month (November 2000) of geologic fieldwork that I think I shall every experience; Drs. Mehrab Khan and Khalid Mahmood of the Centre of Excellence in Excellence in Mineralogy, University of Balochistan, who generously provided access to materials in their vast collections as well as personally guided me through central and northern Balochistan; Khawar Akbar of the Geological Survey of Pakistan (GSP) – Karachi

who took me through southern Balochistan; Asif Rana, Syed Ghani, M. Sadiq Maklani and Dr. Wazir Khan at the GSP – Quetta; and to Mian Sayed Badshah, Ihsan Afridi and Ahmad Ali Shah of the Federally Administered Tribal Areas Development Corporation (FATADC) for arranging my field excursions through the Waziristan and Kurram agencies.

In India, I would foremost like to thank Dr. Rajesh Sharma at the Wadia Institute for Himalayan Geology, Dehra Dun for providing much guidance as well as many samples. Thanks also to Dr. Manoj Pandit, Department of Geology, University of Rajasthan-Jaipur; Ajay Kumal, Geological Survey of India (GSI) – Jammu; N.L. Sharma, GSI – Chandigarh; and N.K. Sood, GSI – Jaipur; and Dr. K.C. Tiwari of the Department of Geology, MSU, Vadodara for his good advice and Amit Sharma (MSU Geology graduate) for his assistance in locating and sampling various material sources in Kutch and Panchmahals, Gujarat.

Back home in Madison I would like to thank Robert Agasie and Kevin Austin at the University of Wisconsin's Nuclear Reactor Laboratory for running so many samples for me as well as Dr. John Fournelle at the Electron Microprobe Lab, Department of Geosciences.

Financial support for various aspects of this research was generously provided by the Harappa Archaeological Research Project, the America Institute of Pakistan Studies, Fulbright-IIE, the George Franklin Dales Foundation, the Graduate School of the University of Wisconsin, the US Department of Energy Reactor Sharing Program, the Wenner-Gren Foundation (Gr. 7066) and the National Science Foundation (BCS-0327246).

Lastly, I wish to thank my undergraduate advisors at Humboldt State University – Professors Llyn Smith (Anthropology) and Paul Blank (Geography), as well as with Tony Rossi (Lecturer, Geography). The seeds of this dissertation were sown in their classrooms.

This dissertation is dedicated to my wife Veronica and my parents Douglas and Sue Ellen for their love, support and patience.

Te amo.



Prof. Dr. Syed Hamidullah, near Jamrud, NWFP, December 2000

Prof. Dr. Syed Hamidullah, Director – National Centre of Excellence in Geology, University of Peshawar, was to have been featured prominently in my acknowledgments section to this dissertation. Besides being a great friend and teacher, he was instrumental in helping me to secure the necessary permissions to do field research in some of the more restricted and difficult to reach parts of Pakistan. Without his guidance and support I would not have learned and I could not have accomplished even one half of what I did.

On October 15th 2005, Prof. Hamidullah died in a helicopter crash while taking part in relief efforts for the victims of the October 8th 2005 earthquake in northern Pakistan.

This dissertation is also dedicated to him.

Chapter 1

Objective, overview and theory, Harappa and lines of inquiry

Chapter 1 – Objective, overview and theory, Harappa and lines of inquiry

Chapter introduction – The principal research objective

This dissertation is an examination of inter-regional interaction and urbanism in the Greater Indus region[1] of Pakistan and northwestern India from the mid-fourth through the early second millennium BC – a period that encompassed the development, existence and decline of South Asia's first urbanized society, the Indus Civilization (ca. 2600 to 1900 BC). The principal research objective has been to identify the sources (geologic provenience) of rock and mineral (stone and metal) artifacts excavated at Harappa, which is a site that grew to become one of the largest Indus Civilization cities. Provenience determinations are used to address *three lines of inquiry* into the inter-regional and intra-site socio-economic relationships of those who dwelled at Harappa during different periods in its history:

1) *Who in the Greater Indus region or beyond were the residents of Harappa interacting with when they acquired rock and mineral resources?*

2) *How did inter-regional interaction/acquisition patterns change over time?*

3) *Did synchronic variations in rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

Underlying this study is the simple premise that rocks and minerals, from the prestige materials used to create items that signified wealth and social status to the utilitarian materials necessary to carry out day-to-day tasks, were integral to the development and functioning of early urbanized societies. The need to acquire these vital resources would have been a major impetus for interaction between the first city-dwellers of the Indus Valley, which is a region where stone and metal sources are scarce or absent,

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[1] see definition on p. 62

and peoples of the neighboring highlands where they occur. Moreover, power garnered from the control of such resources would have been a significant factor in promoting and maintaining the social and political stratification characteristic of an urbanized society like the Indus Civilization. Elucidating rock and mineral acquisition networks through provenience studies of stone and metal artifacts is also an excellent method with which to examine the broad-scale communication and exchange phenomena that Joseph Caldwell conceptualized (1964) as *interaction spheres* (also called *interaction systems* – Shaffer 1992: 442). Archaeologists have come to regard this form of inter-societal contact as an important stimulus for socio-cultural change and innovation (Schortman 1989: 52; Trigger 1989: 330-337). The current state of research indicates that urban lifeways in northwestern South Asia emerged in a milieu of regionally distinct cultures that maintained contact with one another through extensive trade networks and seasonal migration regimes (Kenoyer 1991a; Mughal 1990; Possehl 1990; Shaffer 1992). The resultant urbanized society was characterized by a complex series of internal interaction systems (Kenoyer 1995b), some of which articulated externally with other complex interaction spheres outside of the Greater Indus region (Edens 1993; Hiebert 1995; Lamberg-Karlovsky and Tosi 1973; R.P. Wright 1984). It has been proposed (Possehl 2002, 2007) that the Indus Civilization was part of an even larger, trans-regional system – the "Middle Asian Interaction Sphere," which connected societies from Mesopotamia to the Indus Valley during the third millennium BC. These varying spheres of interaction and the emergence of urbanism in the Greater Indus region are examined here through a series of both broad and fine-scale geologic provenience studies of Harappa's rock and mineral artifact assemblage.

In order to address this dissertation's three lines of inquiry, the entire assemblage of stone and metal artifacts recovered by the Harappa Archaeological Research Project (see p. 31) since 1986 was categorized, periodized and quantified. Nearly 3000 of those artifacts representing eight different rock or mineral varieties were directly compared to geologic samples collected from potential source formations located across the Greater Indus region. Comparative methods ranged from examinations of basic macroscopic and mineralogical attributes to highly precise and accurate isotopic and elemental assays. In the end, provenience determinations for over 2100 stone or metal artifacts were generated.

The large body of new data produced for this dissertation has permitted the testing of numerous hitherto untested assumptions regarding where it was that Indus Civilization peoples, their Early Harappan predecessors and their Late Harappan successors, acquired rock and mineral resources, who they were interacting with as a consequence and how such resources were distributed in an urban setting. Many findings corroborate widely held views of resource acquisition and inter-regional interaction during the late-prehistoric period in northwestern South Asia. Other findings, however, require that certain assumptions be revised. For instance, multiple lines of evidence now point to the existence of early and enduring acquisition networks between Harappa and source areas to the north of the Indus Valley, which suggest that relations with the peoples of that region were more significant than was generally supposed. Synchronic spatial examinations of Harappa's assemblage were also revealing. It appears that, by and large, residents of all parts of the settlement had access to the same varieties of raw materials from the same sources. However, a few variations are evident that suggest groups in some areas of the site may

have, at times, favored materials from certain sources and/or controlled specific kinds of stone. Finally, it has been determined that, during every period at Harappa, some rocks and minerals were derived from sources outside of the Greater Indus region, thus indicating that external trade was an important and continuous aspect of the socio-economic lives of the site's residents. Most of those external sources were located in neighboring highland areas, however. Evidence for external trade with distant regions such as Arabia and Mesopotamia remains, at least in terms of the stone and metal artifact assemblage at Harappa, elusive.

Although the primary focus of this dissertation is Harappa's rock and mineral assemblage and the urban phenomenon at that site, the data generated are pertinent to the broader issue of inter-regional interaction and its relationship to the initial manifestation of urbanized society in South Asia. In order to bolster a broad-scale perspective, this study has been supplemented with geologic provenience analyses of select stone and metal artifacts from over a dozen other prehistoric sites in Pakistan, India, Afghanistan and Iran. These data, although limited, have revealed (or confirmed) the existence of several broad-scale inter-regional resource acquisition networks as well as more localized regional ones.

In this chapter, I first provide an overview of the Indus Civilization. The theoretical orientation from which the issues examined in this dissertation are approached is then laid out in discussions of urbanism and its preconditions, inter-regional interaction, long-distance trade and the control of essential resources, the importance of rock and mineral resources to urbanized societies and the utility of geologic provenience studies in research of this kind. The physical and cultural/chronological aspects of Harappa are then presented. Lastly, the three lines of inquiry are reviewed and a dissertation outline is provided.

Indus Civilization overview and theoretical orientation

The Indus Civilization

In the 1920s and 30s, excavators at the sites of Harappa (Vats 1940) and Mohenjo-daro (Marshall 1931b) exposed the remains of a civilization in northwestern South Asia that was roughly contemporaneous with those of Sumerian/Akkadian Mesopotamia and Old Kingdom Egypt (Figure 1.1). This previously unknown society possessed the most well-planned and maintained cities of its era, a system of writing and standardized weights and measures, technologically advanced craft industries and other aspects of a distinctive material culture that, because they were so remarkably similar across a broad geographic expanse, indicated the existence of a widely shared ideology maintained through extensive trade and communication networks. Although its cultural roots were initially believed to lie in western Asia (it was first designated the "Indo-Sumerian" Civilization – Marshall 1924: 528), it was soon recognized (Marshall 1928) that this society, which has since come to be known variously as the Indus, Indus Valley, Harappan or Sarasvati-Sindhu Civilization (I hereafter use *Indus Civilization*), was fundamentally indigenous in origin.

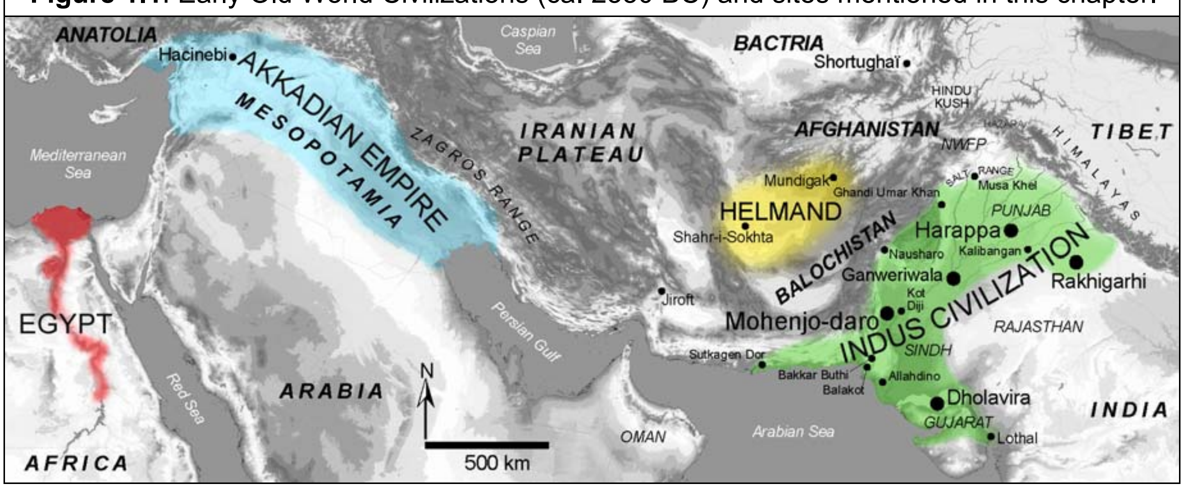


Figure 1.1: Early Old World Civilizations (ca. 2350 BC) and sites mentioned in this chapter.

The Indus Civilization was also, for a great many reasons, an enigma to scholars. Although it was undeniably a complex and highly integrated urbanized society, it lacked certain features exhibited by other early civilizations that were indicative of pronounced social stratification and institutionalized authority. There were no palaces, opulent tombs or large temples that could be associated with either a secular or religious elite ruling class. Nor were there any explicit expressions/depictions of political power such as monuments or murals. Evidence for organized warfare or any other form of violent coercive behavior was practically non-existent. In short, there were few *overt* archaeological indications as to either who governed this society or how they amassed the power and authority to do so. Written records, which had provided valuable insights into these aspects of early Egyptian and Mesopotamian civilizations, were of no help as the Indus script could be not read. Researchers were, therefore, faced with a purely archaeological record of a complex society that was, in several significant ways, at odds with the suite of traits (first outlined by V. Gordon Childe in 1950) then generally regarded as typical of urbanized civilizations.

Interpretations of that record by Sir John Marshall (1931b), Ernest Mackay (1948), Sir Mortimer Wheeler (1950), Stuart Piggott (1950) and others were remarkably astute and, in a great many respects, are still benchmarks for understanding the Indus Civilization. However, they are also products of a nascent era – both in terms of archaeological inquiry in general and South Asian archaeology in particular. In trying to reconcile the somewhat atypical (and then quite limited) record of the Indus Civilization with those of other ancient urbanized societies, early scholars came to some disputable conclusions. For example, their characterizations of Indus society as exhibiting "complete uniformity" (Marshall

1931a: 91), "monotonous regularity" (Piggott 1950: 136) and "astonishing sameness" (Wheeler 1950: 29) across the area in which it is found are, for the most part, significantly overstated (Possehl 1992b). High areas at sites were often regarded as defensive "citadels" and certain large structures as state "granaries" when, in fact, there is little evidence that such features served those purposes (Fentress 1984; Kenoyer and Meadow *in press*; Possehl 2002b: 103-104). A few rare incidences of human statuary at Mohenjo-daro were thought by some to be depictions of austere "priest-kings" who wielded "autocratic and absolute power" (Piggott 1950: 153). In actuality, it is not possible to say who such statuary depicted or if (and much less how) they ruled Indus society (Possehl 2002b: 115).

Our knowledge of the Indus Civilization grew tremendously during the latter half of the 20th century. Surveys brought to light well over 1000 Indus settlements and more than 100 of those sites were excavated (Possehl 2002b: 63). Moreover, investigations and comparative studies of ancient civilizations around the world have significantly broadened our understanding of how early complex societies developed and of the social, economic and political variations that they exhibited (Trigger 2003). Yet early in the 21st century the Indus Civilization remains as enigmatic as it ever was. Its script has resisted all attempts at decipherment (Parpola 1994) and many fundamental questions about its origins, existence and decline remain to be answered. Chief among these questions concern the development and nature of the extensive networks of inter-regional interaction that permitted an urbanized society to emerge and then be maintained for roughly a 700 year period across the culturally and geographically diverse landscape of northwestern South Asia (Allchin and Allchin 1997; Chakrabarti 1984; Fairservis 1975; Gupta 1999; Kenoyer 1998; Mughal

1990a; Possehl 1999; Shaffer and Lichtenstein 1989). It is this issue that is at the core of this dissertation and which I am examining through geologic provienance studies of rock and mineral artifacts from Harappa and other prehistoric sites.

Urbanism and its preconditions

The Indus Civilization represented the initial manifestation of urbanized society in South Asia and Harappa was among the very first urban centers to emerge in that region. Throughout this dissertation, I endeavor to be attentive to the subtle but important differences in the meanings of the terms "urban," "urbanism" and "urbanization" (Smith 2003: 12-13 after Fox 1977; see also Cowgill 2004: 527). *Urban* refers specifically to characteristics of cities and their populations while *urbanism* is used in reference to the "general phenomenon of cities" (Smith 2003: 13). *Urbanization* refers to the emergence of cities within a "territorial expanse" and the process by which peoples of that area, whether they dwell in a city or not, become linked in a "center dominated ethos" (ibid.).

Despite the efforts of scholars in a wide range of fields, "no universal or comprehensive definition of the city" has ever been formulated that can encompass the "specificity and uniqueness" exhibited by all of its historical variants, most especially those in ancient South Asia (Eltsov 2005: 319). Still, Harappa and other comparable Indus Civilization settlements like Mohenjo-daro, Dholavira, Ganweriwala and Rakhigarhi would undoubtedly be considered cities in all but the most rigid of classification schemes. Their populations are estimated to have been in the tens of thousands – orders of magnitude greater than the typical Indus Civilization settlement; there is evidence at most of them for massive perimeter walls and multiple, well-demarcated neighborhoods; they were centers

where a huge range of specialized crafts were produced using raw materials often brought from sources hundreds of kilometers away; and although no definitive examples of administrative and/or religious institutions (palaces or temples) have yet been identified, there are monumental buildings at several of them that obviously served some very important communal or private functions (Bisht 2000; Chakrabarti 1995; Jansen 1994; Kenoyer 1997a; Mughal 1994a; Nath 1998; Possehl 1990).

Although its most prominent characteristic is the city, urbanism is actually an extra-regional phenomenon consisting of interrelated environmental, demographic, technological and social components (Wheatley 1972). Based on those components, Kenoyer (1991a) defined four *general preconditions for urbanism and the rise of state-level society* in ancient South Asia. I have listed these in Figure 1.2 and emphasized (using italics) several key aspects that I focus on throughout this dissertation.

Figure 1.2: General preconditions for urbanism and the rise of state-level society (from Kenoyer 1991a: 343-349). *Emphasis added.*

1) Diversity of subsistence base and *resource variability* which have the potential for the production of surplus.

2) Development of social and economic *interaction networks* between major ecosystems and resource areas.

3) *Technological capability* to fill specific needs of urban and state-level society.

4) Differentiation in status on the basis of *access to essential resources* and the ability to control distribution of essential resources.

Kenoyer's (1991a) first precondition highlights the necessity of a diverse subsistence base and *resource variability*. The roughly 40 distinct kinds of rocks and minerals found in Harappa's artifact assemblage (Chapter 4) are a testament to the rich and

highly varied geologic resources that were available across northwestern South Asia (discussed in Chapter 2). The development of social and economic *interaction networks* between the different ecological zones and resource areas of that region (Precondition 2) provided, in essence, the glue that bound together (integrated) the widely dispersed peoples of the Indus Civilization and the avenues through which subsistence goods and other essential resources could be distributed to them. Identifying these networks through geologic provenience studies of rock and mineral artifacts from Harappa is the central focus of this dissertation. Among the many *technological capabilities* that had to be developed to fill the specific needs of an urbanized society (Precondition 3) were bullock carts and large river boats (Kenoyer 2004; Miller 2006). Such transportation technologies were required to move goods in bulk sizes and quantities over long distances (Law 2006). Their development and use is examined indirectly through the study of bulk goods like grindingstone (Chapter 5) and limestone (Chapter 11) – the latter of which was, at times, transported over 800 km to Harappa in individual pieces weighing in excess of 100 kg. Differentiation in social status based on *access to essential resources* and the ability to control their distribution is Kenoyer's fourth and final precondition. I argue shortly that rocks and minerals were as essential to the development and maintenance of early urbanized societies as were surplus grain or livestock. The issue of differential access within Indus society to such resources is examined by comparing (in Chapter 4) the rock and mineral sub-assemblages from the various discrete habitation areas at Harappa (discussed below), as well as by attempting to detect intra-site variations in the geologic source proveniences of select material varieties that were used in all parts of the settlement.

All four of the above preconditions were fulfilled in the millennia leading up to coalescence of the Indus Civilization at around 2600 BC. The appearance of cities across northwestern South Asia at that time is indicative of the emergence of a society that was markedly more expansive and complex than the various regional, village-based ones that had existed there before. There is debate as to whether this initial urbanization was an abrupt process (perhaps occurring in a single century – Shaffer and Lichtenstein 1989: 123) or a long and gradual one (Kenoyer 1997a). There is also disagreement as to whether or not the Indus Civilization was a state-level society (see Possehl 1998b and Kenoyer 1994b for opposing views on this issue). Based on evidence that is reviewed in Chapter 2, I take the position that the Indus Civilization was the product of an extended phase of steady developments (occurring circa fourth and early third millennium BC and designated the "Early Harappan" Period by Mughal 1970, 1990a) and that it was probably organized politically as state (or at least an amalgam of city-states). However, the latter issue need not be definitively resolved for this present study of urbanism to move forward. A current trend in research of this kind involves "decoupling our understanding of cities from our assessment of early states" (Smith 2006: 98). The settlement of Harappa grew from one of many small villages located on the alluvial plains of northwestern South Asia to become one of a few major urban centers in that region. What I seek to shed light on through the study of its rock and mineral artifacts are the local, regional and extra-regional *actors* – the different groups of people residing at the site itself and those peoples (both Harappan and non-Harappan) dwelling in regions often great distances from it, who were involved in the urbanization process and, specifically, their connections (interaction) with one another.

Inter-regional interaction, long-distance trade and the control of essential resources

The vast geographic area across which Indus Civilization settlements are found and the highly similar material culture attributes that those sites exhibit together point to the existence of well-developed and far-reaching inter-regional interaction networks binding the civilization's "various social groups as a distinct cultural entity" (Shaffer 1988: 1316). It is through such networks that peoples from distant regions come into contact with one another, material resources are transferred from places where they are abundant (or present) to places where they are scarce (or absent), and "ideas are exchanged, inventions are transmitted, and so are ambitions and aspirations" (Renfrew and Bahn 1996: 336). Their establishment and/or intensification is widely believed to have been an important stimulus toward the development of new and increasingly elaborate forms of social and political organization in many parts of the ancient world (Algaze 1989; Chang 1986; Childe 1950; Dematte 1999; Earle 1991; Feinman and Nicholas 1992; Kenoyer 1995b; Lamberg-Karlovsky 1972; Rathje 1971; Renfrew 1986; Schortman and Urban 1992b; Stein 2002). My objectives are to identify the inter-regional interaction networks of the Indus Civilization (at least some of them); to determine if and how they were transformed during the emergence and existence of that society; and to examine the possibility that certain groups of people living at Harappa controlled or had greater access to particular networks.

Inter-regional interaction may occur in various forms, such as "trade, warfare, migration, or the diffusion of ideologies" (Stein 1999: 3). All of these no doubt took place during the period that the Indus Civilization emerged and existed. Some forms, however, appear to have been more significant than others in terms of their role in the development

and maintenance of that urbanized society. For example, while there were almost assuredly violent confrontations (warfare) between late prehistoric peoples dwelling in different parts of northwestern South Asia, there is no evidence that a level of conflict existed similar to that which accompanied the formation of Uruk city-states in Mesopotamia (Gat 2002) or the unification of Early Dynastic Egypt (Wilkinson 1999). Nor are there any iconographic depictions of captives or conquests that would suggest the integration of Indus society was preserved through any form of "military coercion" (Kenoyer 1991a: 347). The peaceful movement (migration) of pastoralists and various "itinerant" peoples (Possehl 1999: 14-16) was likely a more influential form of interaction. Starting in the early Neolithic (ca. 6000 BC), pastoralists established patterns, which continue to this day, of seasonal, long-distance migration between the plains of the Indus Valley and the highlands surrounding it (Bozdar et al. 1989; Fairservis 1975: 210; Meadow 1996). It was such groups that probably did the most to physically connect the disparate regions of South Asia by conveying material resources between them (Law 2006: 306-308; Possehl 1979: 448; Shaffer 1978: 153). However, the transmission of a set of core beliefs and principles (diffusion of ideology) may have played an even greater role in terms of socially/culturally integrating the widely dispersed and ethnically diverse (Shaffer and Lichtenstein 1989) peoples of those regions. The broad dissemination and strong reinforcement of a distinctly "Harappan" ideology (Miller 1985) is evident in the highly similar ways in which Indus Civilization peoples organized their settlements, buried their dead, used iconography, selected raw materials and fashioned their ornaments and implements. The trouble is that this form of interaction is difficult to document with a reasonable degree of spatial or temporal precision.

The exchange of material resources or finished goods (trade) is the most commonly studied form of ancient inter-regional interaction (Schortman and Urban 1992a: 236). Although this is no doubt due, in part, to the fact that it tends to be the most archaeologically visible form (and thus the easiest to document), long-distance trade is also a frequent subject of examination because of the influence it is thought to have often had on the social and political development of peoples who engaged in it (Adams 1974; Curtin 1984; Earle 1982; Kipp and Schortman 1989; Hirth 1978; Renfrew 1975; Shaikh 1991; Vikrama 2002; Webb 1974). It is an activity that is born of a society's (or of certain peoples within a society) need or desire to acquire materials/items that are scarce or absent in the region where they live. Those may range from subsistence resources and utilitarian items that are used by all of its members to exotic materials or manufactured goods that might only be used by a select few (Pires-Ferreira and Flannery 1976: 287-289). Long-distance trade provides individuals or social groups with opportunities to enhance their own wealth and/or societal status by taking control of how imported goods are distributed. The "social power" (Mann 1986) that they garner by doing this fosters social/political stratification within their society. Kenoyer (2000) argues that those people(s) who, over time, came to rule Indus Civilization cities acquired the power to do so, in large part, by controlling both access to essential raw materials and the manufacture/distribution of status-defining items. The kinds of raw materials (imported vs. local) and the technologies (complex vs. simple) that were used in these regards varied considerably (Kenoyer 1995b: 217; Vidale and Miller 2000). Likewise variable was the nature (prestige-related vs. utilitarian) of the materials controlled and of the goods manufactured/distributed. In the next section, I discuss how imported

materials (specifically rocks and minerals) of both natures were vital to the political economies of Indus Civilization cities like Harappa. However, it is not my intention to focus on *how* such materials were employed in the power strategies that facilitated the development and reinforcement of the first urbanized society in northwestern South Asia. Rather, it is to use them to ascertain *who* was involved, even indirectly, in that process.

Regions do not interact with one another, people living in different regions do. By identifying the trade networks through which residents of Harappa were importing rocks and minerals I seek to ascertain who it was that they were interacting with. Some of those people would have also belonged to the Indus Civilization. I refer to them throughout this dissertation either as *Indus Civilization peoples* or as *Harappans* (after the type site of Harappa). The latter term is more frequently used by scholars (and is more convenient). Unless the context makes it clear, I refer to those Harappans who lived at Harappa as *residents of Harappa*. In Chapter 2, I provide details regarding the complex mosaic of regional cultures that existed across northwestern South Asia during the millennia prior to the emergence of the Indus Civilization. These peoples are referred to separately by their various regional designations and collectively as *Early Harappans* (following Mughal's [1970] convincing argument that they were all cultural antecedents to the Harappans). Also in Chapter 2, I discuss various *non-Harappan* cultures (and non-Early Harappan ones) that dwelled in regions adjacent to Indus Civilization peoples. Even though these groups were not integrated into the urbanized society of their neighbors, they were nonetheless vital contributors to it because it was from their territories that many of the resources essential to its development and maintenance were derived.

Fernand Braudel remarked (1966: 29) that the historian tends to "linger over the plain … and does not seem eager to approach the high mountains nearby." The same could have once been said of archaeologists investigating early civilizations in the Near East and South Asia. The "highlands" (defined in Chapter 2) adjacent to the broad river valleys of those regions, while never entirely ignored, did not figure significantly in early concepts of how or where urban lifeways developed. Perceptions began to change when, starting in the 1950s, surveys and excavations in the lands between Mesopotamia and the Indus Valley – i.e., Iran, Afghanistan and Balochistan, revealed that their ranges and elevated basins were home to complex and, at places like Shahr-i-Sokhta, urbanized societies (Casal 1961; Dales 1976; Fairservis 1975; Lamberg-Karlovsky 1986; Shaffer 1978; Tosi 1982). As a result, the nature and extent of interaction between the peoples of those regions and their lowland contemporaries became an important topic of inquiry (Beale 1973). Urbanism in this part of the ancient world is now regarded to have been an extra-regional phenomenon in which highland "Middle Asia" was a significant component (Possehl 2007).

Several scholars (Algaze 1993; Dhavalikar 1995; Edens 1992; Kohl 1979) have advocated the use of "world-systems" theory (Frank 1993; Wallerstein 1974) as a model for examining trade and cultural development across a zone stretching from "the Nile to the Indus Valley in the 4th and 3rd millennium BC" (Kohl 1978: 475). In this scheme, complex and powerful "core" societies (such as the Uruk of Mesopotamia or the Indus Civilization) requiring raw materials not available in their territories are seen as engaging in exploitative, asymmetrical exchange relationships with less developed and less powerful cultures in resource-rich "peripheries." The political-economies of those peripheral societies are

viewed as being structured by this relationship with the dominant core, which controls them either directly (colonially) or indirectly (through local rulers whose power is dependent on trade goods from the core). Although world-systems analysis does constitute a holistic macro-regional model with which to examine inter-regional interaction, recent critiques (Ratnagar 2001a; Stein 1999) of its application in this part of the Bronze Age world (cited above) have found that key aspects of it – notably the assumption of a dominant core and the idea that asymmetrical long-distance trade with it imposes "structured inequalities" upon the peripheries (Ratnagar 2001a: 352), are not really borne out by the archaeological record of that region. Below are just two brief examples related to Uruk Mesopotamia.

At the site of Hacinebi in the Taurus Piedmont of southern Anatolia, a small but long-lived Uruk trading enclave was documented to have existed among the settlement's local Chalcolithic population (Stein et. al 1996). No evidence for inter-societal conflict or competition was recovered there that might indicate "the Mesopotamians dominated their Anatolian host community" (Stein 2002: 912). In fact, the far-flung enclave's very survival was almost certainly dependent on its members "remaining on good terms with their more powerful (in relative local terms) indigenous neighbors" (ibid.: 909). Similarly, Elizabeth Henrickson's study (1994) of Uruk relations with Chalcolithic cultures dwelling in the Zagros Mountains of western Iran indicated that the people from the politically more complex lowland society did not dominate the comparatively less complex highlanders from whom they were obtaining a range of important resources. The evidence instead suggested that the Mesopotamian "highland strategy" was one of "balanced trade and accommodation instead of brute force" (Henrickson 1994: 98).

There is good reason to believe that Harappans likewise did *not* dominate societies dwelling in the "peripheries" from which they acquired raw materials. As previously discussed, violent coercion was evidently not the means through which the widely dispersed and ethnically diverse peoples of the Indus Civilization were initially integrated into an urbanized society or how that integration was maintained for 700 years. It seems, therefore, unlikely that Harappans would have employed such a radically different and uncharacteristic strategy as that in their dealings with non-Harappan cultures in regions outside of their homeland. Moreover, even if Harappans had wanted to dominate peoples in the highlands surrounding the Indus Valley, which is where a substantial portion of the raw materials they used occurred, it is unlikely that they would have been able to do so – at least not for very long. Mountainous regions are notoriously precarious places that are often home to societies over which lowland "civilizations" have time and time again failed to establish and/or sustain any significant degree of control (Braudel 1966: 38-41). In South Asia's modern era this is exemplified in the Afghanistan-Pakistan borderlands region, where there are still today Pathan (Pukhtoon) tribes that have never been entirely subjugated despite repeated attempts by a succession of empires and nations (Hussain 2000).

When Harappans traveled outside of their homeland in order to obtain raw materials, instead of dominating and exploiting peoples of a "passive periphery" as world-systems theory would predict, they likely encountered populations of "active agents" with whom it was necessary to establish some form of mutually satisfactory exchange relationship (the quoted text is from the title of Gil Stein's 2002 review of this subject). That, at least, is the assumption I am making based on the studies and observations

discussed above. In this dissertation, I will not be attempting to test if the nature of Harappan long-distance trade did or did not conform to the world-systems model (or to any alternate model of inter-regional interaction). To do so would require data on the control of goods and resources within its so-called "peripheries." The primary archaeological dataset that I am using (from the site of Harappa) would be considered representative of the "core." Geologic provenience studies conducted on it serve only to identify the regions from which residents of Harappa acquired rocks and minerals. Who actually controlled resources in those regions is not determinable using such data. I wish to emphasize this point because such control is sometimes assigned to Harappans without sufficient evidence. For example:

In northern Afghanistan, Harappan "control of … highland peoples and resources may not have been as great as supposed by some" (Francfort 1985: 129). Shortughaï is an Indus Civilization outpost located in that region at the foot of the Badakhshan Mountains (Francfort 1984b). Although there are a half-dozen non-Harappan Bronze Age settlements in its vicinity (Lyonnet 1977), none have yet been excavated. Understanding the actual nature of the Harappans' relationship with the indigenous population of the region has, therefore, proven problematic (Francfort 1984a). It has been suggested that Shortughaï was established to "control the mining of lapis lazuli and other precious materials from this area" (Allchin and Allchin 1997: 168). However, other than the fact that, 1) lapis lazuli was worked at the site and that, 2) it is the nearest Indus Civilization settlement to a source of that stone (although it's still hundreds of kilometers from and thousands of meters below the actual deposits), there is really no evidence to demonstrate that Harappans *controlled* the extraction and distribution of that or any other raw material from northern Afghanistan.

The control of essential resources is a key issue in this study because, as previously discussed, the social power that groups and individuals derived from it is one of Kenoyer's (1991a) four general preconditions for the rise of urbanized, state-level society (Figure 1.2). Control of raw material sources is best supported when there are clear material culture associations with extraction areas, such as there are at chert quarries in the Rohri Hills of Sindh (discussed in Chapter 6) or at some limestone quarries near Dholavira in Gujarat (discussed in Chapter 11). Such instances are, unfortunately, very rare – the two just mentioned are the only ones that I am aware of associated with the Indus Civilization. Although an archaeological site may be situated fairly close to a raw material source, proximity alone does not demonstrate control. Of course, if a source is surrounded by sites that all belong to the same cultural "phase" (see definition pp. 73-74) then it is reasonable to assume that peoples of that phase probably had some degree of control over it. However, the situation is not always that clear cut in most of the regions from which I show that residents of Harappa were acquiring their rock and mineral resources. In many cases, material sources are located in zones where different cultural phases came together. Other times they are found in places far from where any archaeological sites have been identified. It is for these reasons that when addressing questions related to the control and distribution of essential resources I focus on the only contexts that I am studying where a very strong case for such control can be made, which are – the different walled habitation mounds that together make up the site of Harappa. In upcoming sections of this chapter, I discuss these walled mounds and outline what I have attempted to learn by comparing the different sub-assemblages of rock and mineral artifacts recovered from them.

This study was inspired, in part, by Catherine Jarrige and Maurizio Tosi's (1981) paper "The Natural Resources of Mundigak," in which they defined the "economical space" of that Bronze Age site in southern Afghanistan by listing the probable sources for the full range of raw materials excavated there. I have adopted a similar broad-scale perspective for this project, which, on a basic level, is a straightforward effort to delineate the rock and mineral resource catchment area of Harappa. However, I have tried to keep in mind an observation about studies of inter-regional interaction made by the late Prof. George Dales:

> The ultimate significance of inquiries such as this is not just to play intellectual games with bits and pieces of ancient castoffs and debris. … What we would really like to know is the nature and extent of these relations. Just how cognizant were the citizens of each region of the peoples and cultures of the others? What degree of dependence – if any – was involved? (Dales 1968: 22).

Dales' comments serve to remind that this is also an examination of ancient inter-cultural relationships. In order to have acquired many of the resources that were essential to their urban lifeways, Harappans had to have interacted (either directly or through intermediaries) with peoples in regions that were outside of their homeland. Although the nature of those relationships cannot be determined at this time, it is argued that Harappans were heavily dependent upon them because of the vital role that imported resources played in their political economy (discussed below). It is also argued that because of this, the non-Harappan cultures of the Indus Civilization's hinterlands should be regarded as among the actors that played a part, if only an indirect one, in the maintenance of Indus urbanized society. One of the aims of this dissertation is to identify and evaluate the significance of these inter-cultural relationships by studying the trade of essential raw materials.

Nayanjot Lahiri remarked that a “qualitative leap in studies of trade [in ancient South Asia] can happen only if detailed and large-scale scientific studies on different kinds of artefacts and their raw material sources are undertaken” (Lahiri 1992: 6; Chakrabarti [1990: 141] expressed a similar opinion). Recent decades have seen some important steps in this direction. Systematic and/or archaeometric examinations of Harappan resource acquisition and long-distance trade have been conducted on marine shell (Kenoyer 1984b), subsistence goods (Belcher 1998), ceramic vessels (Méry and Blackman 1999) and stoneware bangles (Blackman and Vidale 1992). However, other than a few limited and inconclusive comparisons of copper ore sources and copper-alloy objects (which I discuss in Chapter 12), there has been a “dearth of research” on this subject involving rock or mineral artifacts (Kashyap 2005: 7). This dissertation is an effort to rectify that situation.

Rock and mineral artifacts and geologic provenience analysis

Of the many categories of materials that peoples exchanged in antiquity, items made from rocks or minerals (stone and metal artifacts) are perhaps the best suited to studies of inter-regional interaction and urbanism – for two reasons. Firstly, both prestige and utilitarian (designations discussed below) rock and mineral goods were vital to the *political economies* (“the material flows of goods and labor through a society, channeled to create wealth and to finance institutions of rule” – Earle 2002: 1) of complex hierarchical societies like the Indus Civilization. Secondly, such artifacts are particularly well-suited to studies aimed at reconstructing resource acquisition networks by identifying the place of origin, or *geologic provenience*[1], of the raw material from which they are composed.

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[1] as opposed to an artifact’s *archaeological provenience* – meaning the specific archaeological context from which it was recovered, or *provenance* – its history subsequent to its recovery.

Exotic (rare) rocks and minerals and the items fashioned from them are among the most important kinds of *prestige* goods. Such goods were used as objects of wealth as well as markers of status, identity and authority (Brumfiel and Earle 1987; Helms 1993; Hayden 1998; Kenoyer 2000; Trubitt 2003). Although most Harappan stone and metal artifacts of this nature are notable for their small size, I argue later (in Chapter 11) that certain large and heavy objects like limestone ringstones were likely prestige-related. In terms of the political economies of early urban societies like the Indus Civilization, the acquisition of "exotic goods must be seen in the same ways as the accumulation of grain or livestock" (Kenoyer 1991a: 345). Using wealth and influence gained by the control of those goods, individuals or groups governing a society could finance and reinforce institutions of rule. However, rulers that relied too heavily on such a "wealth finance system" (Earle 1991) might find their positions compromised by an interruption in the flow of exotic materials.

Harappans would have required many different kinds of *utilitarian* stone and metal implements in order to carry out innumerable common, day-to-day tasks associated with living and working in an urbanized society. Having reliable access to the resources needed to make them would have been a significant concern for those dwelling at settlements in the Indus Valley proper as there are few sources of stone in that region (there are none at all within 120 km of Harappa – discussed in Chapter 2). The need would have been particularly acute at Harappa itself, which was both a center for numerous craft industries and home to a large urban population. Agate nodules brought to the site from Gujarat (Chapter 8) could not have been transformed into beads with high prestige value unless a range of utilitarian stone was also available to make the different tools needed for chipping,

perforating and grinding them. Enough surplus grain to support an urban population could be produced on alluvial plains that surrounded the city, but the heavy sandstone-quartzite querns and mullers needed to process it could be acquired only from geologic formations hundreds of kilometers away (Chapter 5). Monica Smith showed how the demand for "ordinary goods" played a major role in the "development, success, and long-term viability of regional trade networks" during the Early Historic period of central India (Smith 1999: 109). The need for "ordinary" stone by people dwelling in the rock and mineral resource-poor Indus Valley probably had a similar influence on regional trade in that part of South Asia during the Bronze Age. Controlling utilitarian goods may have even been an important and, in ways, more stable (as compared to a wealth finance system) political-economic strategy for ruling elites in the ancient world (Aoyama 2001; D'Altroy and Earle 1985; Schwartz et al. 1999; Wright 1984). Had Harappan elites desired to control "ordinary" rock and mineral resources for their own benefit (i.e., to enhance their own wealth and influence), then the situation in the Indus Valley would have afforded them an opportunity to do that.

It was probably the case that those who governed Indus Civilization cities derived their power to do so, in part, through the control of <u>both</u> "exotic" and "ordinary" goods. However, with a few exceptions, I do not dwell too closely on either the prestige or utilitarian natures of the artifacts examined in this dissertation. As previously stated, it is not my intent to focus on the particulars of how Harappans used rock and mineral resources in their political power strategies. Also, what constitutes a prestige good versus a utilitarian one is not always that clear or absolute (for a detailed discussion of this matter see Smith 1999: 113-114). For the purposes of what I am trying to accomplish, it is important to

recognize that stone and metal goods of *both* natures were essential to the development and functioning of the Indus Civilization and its cities. Furthermore, at a settlement deep within the Indus Valley like Harappa, a rock or mineral artifact's mere presence indicates that someone once decided that it was worth the time and effort to transport it (or worth the expense to acquire it after it had been transported) hundreds of kilometers to the site. In this regard, there are no unimportant artifacts in this material category, in spite of how mundane some may seemingly be. It is for these reasons that I examine, in one way or another, every rock and mineral variety within Harappa's artifact assemblage. This all-inclusive approach reduces the need to draw sharp distinctions between prestige and utilitarian materials. Both were essential and both are examined. Most importantly, this approach provides the broad perspective required to thoroughly address this dissertation's main question: With whom were the residents of Harappa interacting?

In the absence of historical accounts of trade or other forms of inter-regional interaction, geologic provenience analysis can provide compelling evidence that a link (however indirect) once existed between the ancient inhabitants of a region where a stone or metal artifact entered the archaeological record and those in the region where the raw material the artifact is composed of originated. The soundest provenience determinations are ones based on analyses of artifacts composed of unadulterated rock or mineral rather than processed metal, which could contain metal from multiple sources as well as various alloys and additives. With unadulterated stone, "specific types of raw materials can be related to an objective geologic reality that is derived from natural (as opposed to cultural) processes" (Odess 1998: 419). It is for this reason that the artifacts favored for analysis in

this dissertation were raw materials or manufacturing debris. Such artifacts were also favored because they were probably used and discarded during roughly the same period that they were originally acquired and, thus, are likely to represent contemporaneous links between different regions. Finished items (especially ornaments) might have been traded or passed down for decades or even centuries prior to entering the archaeological record.

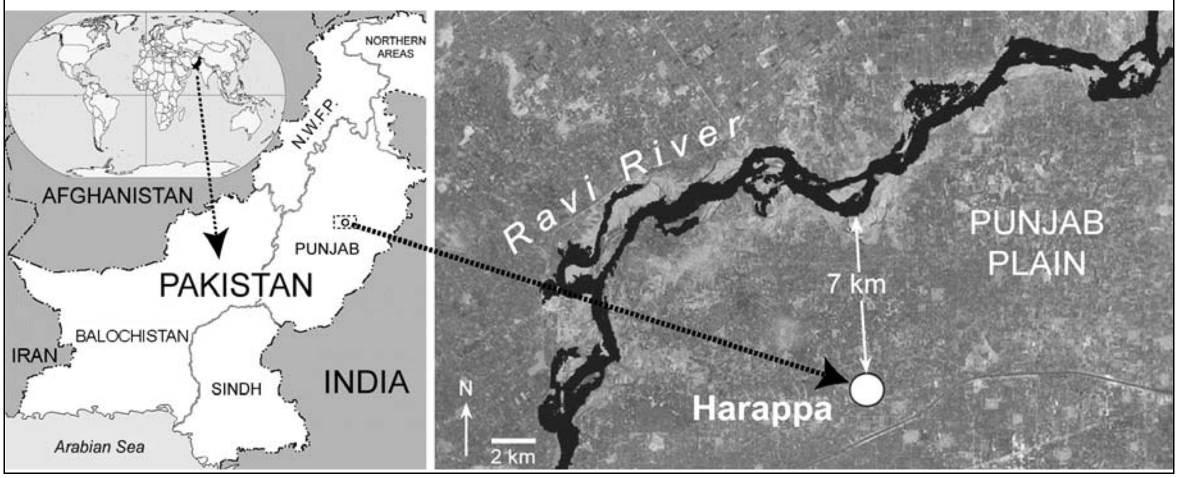
Archaeologists around the world have employed a wide variety of techniques and instrumentation in efforts to identify the geologic sources of an even wider variety of stone and metal artifacts (Henderson 2000; Lambert 1997; Pollard and Heron 1996; Rapp 2002). In Chapter 2, the strategies and methods used in this dissertation are detailed in full. To date, over 2100 geologic provenience determinations for eight main varieties of stone or metal artifacts from Harappa have been generated along with nearly 120 for artifacts from twelve other sites. With this substantial new database on rock and mineral resource acquisition, it is possible to examine inter-regional interaction during the initial manifestation of urbanized society in South Asia in an unprecedented level of detail.

Although it is an extra-regional phenomenon, “urbanism plays itself out most visibly on the local” level (McIntosh 1999: 68). In northwestern South Asia, the site of Harappa is the optimal locale to study it. Harappa’s stratigraphic sequence encompasses the development, existence and decline of the Indus Civilization and, because it was center for numerous craft industries from the time it was established, the abundant remains of rock and mineral resources are found at each stage of its existence. These remains, which have been documented by the Harappa Archaeological Research Project, constitute a dataset that is unparalleled in the region. In the next section, I introduce the site and the dataset.

Harappa

The focal point of this dissertation is the archaeological site of Harappa, located in District Sahiwal, Punjab Province, Pakistan (Figure 1.3). In this section, I discuss the site's general location and layout; provide an overview of the archaeological investigations that have taken place there; introduce its rock and mineral assemblage, which is the primary dataset for this study; and review the site's chronological / cultural sequence in detail.

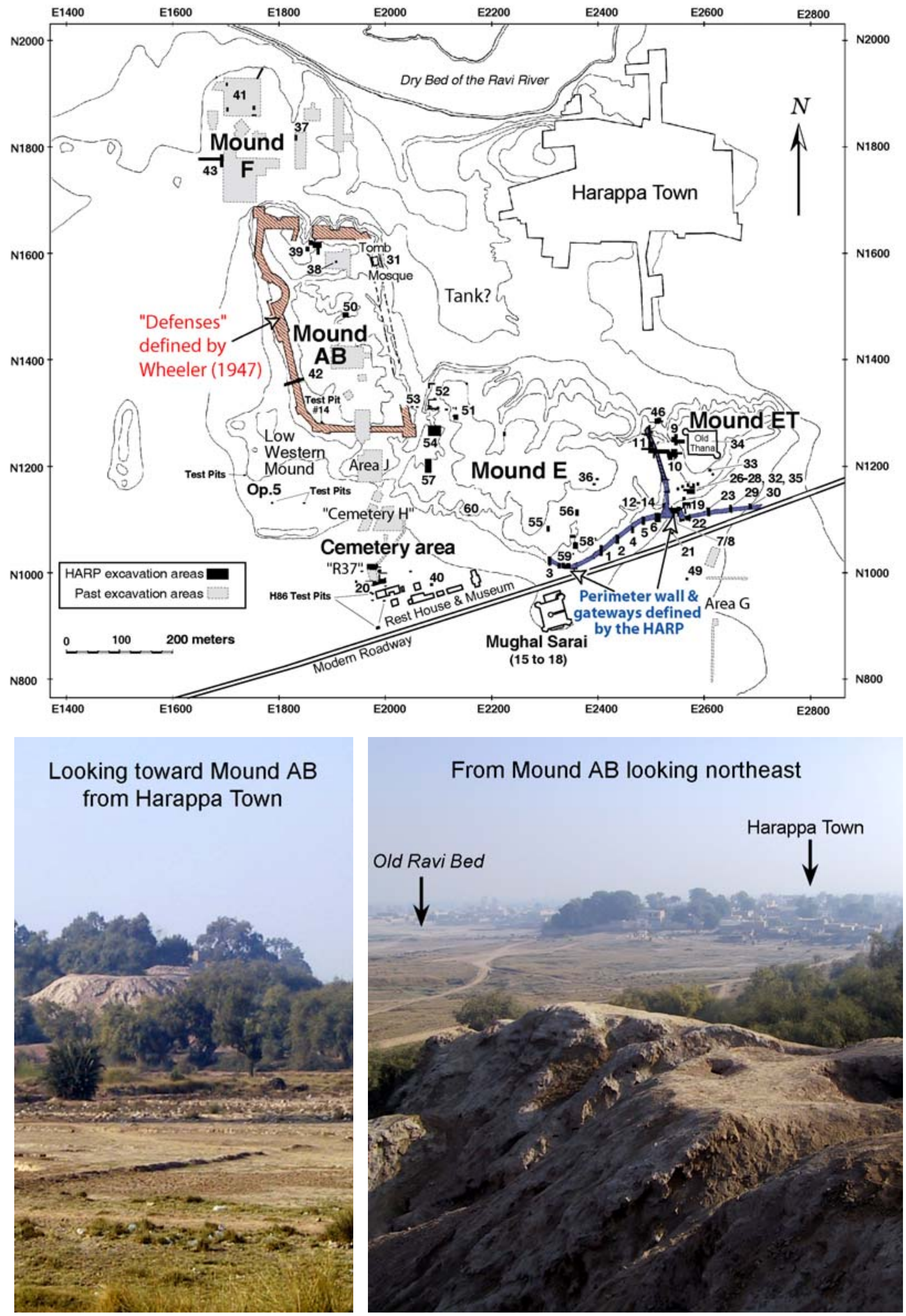
Figure 1.3: Harappa's location today (world map adapted from Wandrey and Law 1998).



General location and layout

Harappa was founded upon an alluvial terrace in the center of the fertile but rock and mineral resource-deficient Punjab Plain of the upper Indus Basin around the mid-fourth millennium BC (full details relating to the site's geologic and geographic contexts are provided in Chapter 2). By the mid-third millennium BC, the settlement had grown to become one of the largest Indus Civilization cities – covering an area of perhaps 150 hectares (ha) at its greatest extent (Dales and Kenoyer 1989a: 72). At that time, the site consisted of several distinct habitation areas, the mounded remains of which rise as high as 17 meters above the surrounding plain (Figure 1.4). The modern town of Harappa sits atop

Figure 1.4: Harappa – site plan and views toward and from the mounds
(This and all subsequent site plans in the dissertation are modified from Meadow et al. 2001: Figure 2)



one of these mounds in the northeast portion of the site. The Ravi River is presently situated seven kilometers to the north (Figure 1.3 *right*) but *may* have been closer in Harappan times. Marking the northern edge of Harappa is an abandoned channel of the Ravi (Figure 1.4), which fills with water during the summer monsoons (Belcher and Belcher 2000).

History of discovery and research

The site of Harappa was "discovered" in 1829 when an antiquarian named Charles Masson camped near the remains of a "ruinous brick castle" while journeying through the Punjab (Masson 1844: 453). Unfortunately Harappa's bricks also attracted the attention of British railroad engineers who, seeking a source of ballast in the stone-free Punjab Plain, systematically plundered them in the late 1850s for the building of the Lahore-to-Multan line (Possehl 1999: 51-52). This destroyed most of the site's post-1900 BC occupational strata and greatly disturbed much of that belonging to the Harappan Period (ca. 2600 to 1900 BC). In spite of the damage caused by "brick-robbing," Sir Alexander Cunningham conducted the first limited excavation at Harappa in 1873 (Cunningham 1875). He also published a plan (ibid.: Plate XXXII) on which the different mounds and areas of the site were assigned letter designations that are still used today (hence mounds AB, E, ET and F on Figure 1.4). During the 1920s and 30s, large-scale excavations were undertaken by Rai Bahadur Daya Ram Sahni (1921, 1926, 1927) and Madho Sarup Vats (1933, 1935, 1936). These form the basis of the "site report" – Excavations at Harappa (Vats 1940). Although several follow-up digs took place over the next few decades, the results remain largely unpublished (Possehl 1991). Important exceptions are Rafique Mughal's excavations in the cemetery area (Mughal 1968) and Sir Mortimer Wheeler's single excavation season of

1946 (Wheeler 1947) during which he defined the walled "defenses" of Mound AB and, in a deep sounding, discovered a pre-Indus Civilization occupation at the site. The areas where excavations prior to 1986 took place are noted in gray on the site plan (Figure 1.4).

In collaboration with the Department of Archaeology and Museums, Government of Pakistan, a program of sustained excavation and research was initiated at Harappa in 1986 – first as a University of California-Berkeley Project under the direction of the late Prof. George Dales and Dr. J. Mark Kenoyer (Dales and Kenoyer 1986b, 1988, 1987, 1989b, 1990b) and then reorganized as the Harappa Archaeological Research Project (HARP) under the direction of Drs. Richard Meadow and J. Mark Kenoyer (Meadow and Kenoyer 1992, 1993; Meadow et al 1994, 1995, 1996, 1997, 1998, 1999, 2001). I hereafter use the acronym "HARP" when referring to the post-1986 excavation program. Marked in black on the site plan (Figure 1.4) and labeled by trench number are the HARP excavation areas.

One of the stated objectives of the HARP is the study of Harappa as a "discrete urban phenomenon" (Dales 1991: 1). Now, after 22 seasons of detailed, question-oriented excavation and research, a great deal is known about how the nature of this particular settlement and the culture of the people living at it transformed over time. These transformations have been documented in the form of changes in site size, architecture, artifact types and artifact forms (Clark 2007; Meadow and Kenoyer 1997, 2001, 2005). Successive innovations in craft technologies have been detected (Kenoyer 1992, 1995b, 2005a; Kenoyer and Miller 2007; Miller 1999) as well as evidence for shifting strategies of faunal (Belcher 2003; Meadow 1991; Miller 2004) and plant exploitation (Weber 1999). Although as yet undeciphered, it is now possible to trace the development and changing

uses of the Indus script at Harappa (Kenoyer 2006; Kenoyer and Meadow 1996). Collectively these studies provide a rich body of contextual information that can be used to inform research projects like this one, which should be considered as another aspect of the ongoing effort by the HARP to understand urbanism at Harappa and in ancient South Asia.

Harappa's rock and mineral artifact assemblage

Harappa was a center for many different kinds of craft activities involving stone or metal (Kenoyer 1992, 1995b, 2005a). To appreciate this one need only to walk across its mounds and look down toward one's feet. Numerous varieties of rocks and minerals (in the form of both finished items and production debris) are evident on the site's surface. They are gathered by the handful during surface surveys (Figure 1.5) and are equally abundant as underlying strata are exposed. By the end of the 2004 field season, some 56,350 stone or metal artifacts had been recovered and tabulated by the HARP. My aim in this dissertation is to make full use of this immense dataset by examining it at multiple scales.

Figure 1.5: Surface survey on Mound E and some of the stone and metal artifacts recovered.



There are certain questions relating to how rock and mineral resources were used and controlled by residents of Harappa that can be addressed only by examining the assemblage on a very broad scale. For example: Was there, in fact, "hardly any major change in the types of raw materials used between the early and mature Harappan" periods as Chakrabarti (1998: 51) has posited? Were groups of Harappans dwelling in different habitation areas (mounds) acquiring the same basic suite of rock and mineral resources? The broad perspective needed to address these kinds of questions is achieved by treating the entire assemblage as a single entity that is made up of multiple "elements" (different rock and mineral varieties), which may or may not vary over space and time. This scale of examination is employed in Chapter 4, when all stone and metal artifacts at Harappa are categorized by material variety and their spatial and temporal distribution patterns are collectively observed. Provenience studies of specific rock and mineral varieties, which are presented in chapters 5 through 12, constitute examinations of the dataset at finer scales. The summary of the individual provenience study results with assemblage spatial and temporal distribution data that is presented Chapter 13 represents a return to a broader scale.

This study is possible because of the well-planned excavation strategy of the original HARP directors who posed many of the same questions I am now investigating and saw to it that all stone and metal encountered during surveys and excavations were collected and contextual information for each individual item was meticulously recorded. When considered in relation to Harappa's increasingly well-understood chronological / cultural sequence (discussed next) this immense, well-documented dataset becomes a powerful tool for examining resource acquisition and inter-regional interaction over time.

Harappa's chronological / cultural sequence

Other Indus Civilization cities have been excavated but none have a chronological sequence that, being based on over 100 radiocarbon determinations (Meadow and Kenoyer 2005: 208-209), is as temporally secure as the one at Harappa. These ^{14}C dates, in combination with a close adherence to the principles of stratigraphic excavation (Kenoyer 1992) and diachronic studies (Dales and Kenoyer 1991; Kenoyer and Meadow 1999, 2000; Meadow and Kenoyer 1994, 1997, 2005, *in press*) of architecture, artifact forms and material culture assemblages, have enabled HARP excavators to reconstruct the site's cultural history in great detail. Five main periods of pre/proto-historic occupation have now been delineated that extend roughly from the mid-fourth millennium BC to the mid-second millennium BC (Figure 1.6). This cultural sequence encompasses the development, existence and later-stage transformations of the Indus Civilization. There are two *Early Harappan* (a chronological / cultural designation that are discussed below and in Chapter 2) phases – the pre-urban *Ravi Phase* (Period 1) and the incipient urban *Kot Diji Phase* (Period 2). These are followed by the fully urban *Harappa Phase* (Period 3 with sub-periods 3A, 3B and 3C). This period/phase is equivalent to the extra-regional manifestation of the Indus Civilization and is often referred in the literature as the "Mature" Harappan

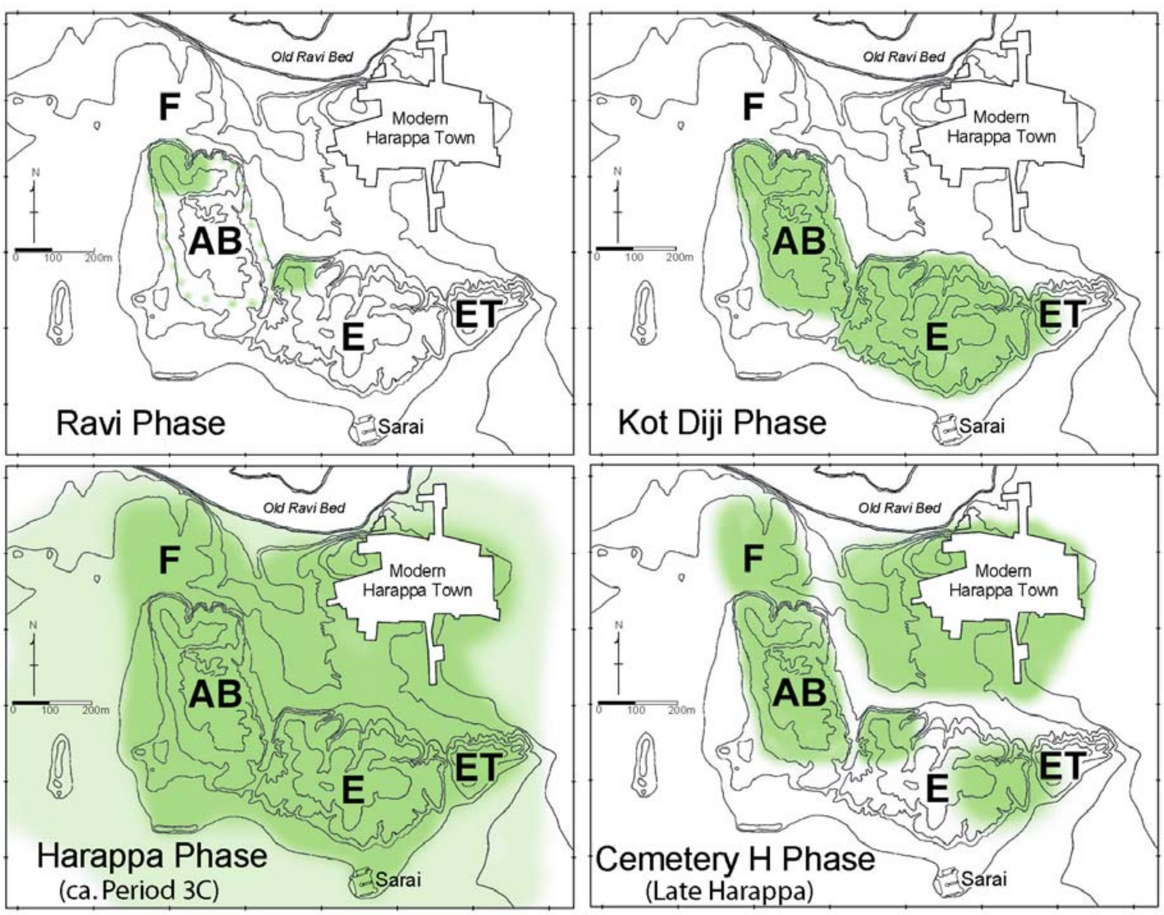
Figure 1.6: Harappa periodization and chronology (after Meadow and Kenoyer 2001)

Period 1	Ravi (Early Harappa) Phase	> 3300 BC - ca.2800 BC
Period 2	Kot Diji (Early Harappa) Phase	ca.2800 BC - ca.2600 BC
Period 3A	Harappa Phase A	ca.2600 BC - ca.2450 BC
Period 3B	Harappa Phase B	ca.2450 BC - ca.2200 BC
Period 3C	Harappa Phase C	ca.2200 BC - ca.1900 BC
Period 4	Harappa/Late Harappa Transitional	ca.1900 BC - ca.1800 BC?
Period 5	Cemetery H (Late Harappa) Phase	ca.1800 BC? - <1300 BC

Period. Here, however, I simply use the term "Harappan" when referring to this phase at the site and in the region. The protohistoric sequence closes with a short transitional phase (Period 4) and the late/post urban *Late Harappa Phase* (Period 5).

The settlement of Harappa underwent significant transformations in terms of size and organization during its two millennia-long protohistoric cultural sequence (Figure 1.7). In the sub-sections that follow, I outline these changes (refer to figures 1.3 and 1.6 as they are discussed) and review the cultural attributes characteristic of each the site's phases and sub-phases. These overviews are intended to be site specific. In Chapter 2, I discuss in detail the regional and extra-regional cultural phases to which residents of Harappa belonged.

Figure 1.7: Settlement growth and decline at Harappa ca. 3300 to <1300 BC



Ravi Phase – Period 1 (> 3300 BC - ca.2800 BC)

The initial occupation (Period 1) at Harappa has been designated the "Ravi" Phase by Kenoyer and Meadow (2000). It is presently known from Trench 39 on the northern end of Mound AB and from a very limited exposure in Trench 52 on the northwestern corner of Mound E. The earliest relevant ^{14}C dates for this period "are not older than c. 3300 calBC" (Meadow and Kenoyer 2005: 209). These dates, however, were obtained from strata that, at the time, would have constituted the northern fringe of the settlement. It is, therefore, quite possible that earlier, more deeply buried levels exist toward the center of the site (ibid.), which is estimated to have been around seven to ten hectares in size (Kenoyer and Meadow 2000: 56). Two sub-periods/phases (1A & 1B) are defined based mainly on changes in ceramic technology that took place over the course of what appears to have been an uninterrupted cultural sequence. The polychrome ceramics used during the earlier part of the Ravi Phase (Period 1A) were all built by hand. Wheel-thrown pots appeared and gradually increased in number during the latter portion of the phase (Period 1B), which merges into Period 2 at around 2800 BC. The transition from 1A to 1B is not well-demarcated stratigraphically. For this reason and because the total exposure for this period is very limited, the rock and mineral artifacts recovered from Ravi Phase levels are, for the purposes of this dissertation, treated as a single, undivided sub-assemblage.

Many cultural features that are hallmarks of the Indus Civilization were already present, at least in rudimentary form, at the Ravi Phase village of Harappa. For example, Ravi Harappans constructed their wattle and daub and mud-brick dwellings with walls that were oriented in the cardinal directions (Meadow and Kenoyer 2001: 22-23), just as later

baked-brick architecture would be at this and other Indus Civilization sites. Many of the graphic symbols they inscribed on their ceramics appear to be precursors to the Indus script (Kenoyer and Meadow 1996; Meadow and Kenoyer *in press*). Although we cannot be certain until more extensive excavations are conducted, the Ravi Phase village of Harappa already *may* have been organized into distinct habitation areas – Mound AB and Mound E (Kenoyer and Meadow 2000). Most significantly, certain Ravi Harappans were acquiring raw materials (marine shell and different varieties of stone) from very distant sources and, using complex craft technologies, transforming them at the site into items that signified wealth and social status (Kenoyer and Meadow 1999, 2001; Kenoyer 2005a).

Developments similar to the ones above probably took place at villages across northwestern South Asia during the fourth and first half of the third millennia BC. Rafique Mughal characterized the various regional cultures with such antecedent Indus Civilization traits as "Early Harappan" (Mughal 1990a). At Harappa, this apt designation is applied to the site's first two cultural phases and to the period during which they existed.

Kot Diji Phase – Period 2 (ca.2800 BC to 2600 BC)

There is no discernible hiatus between Ravi Phase strata and that of the subsequent "Kot Diji" Phase (Period 2) in the two trenches (39 and 52) where they are both present. Ravi-type ceramics were gradually replaced by Kot Dijian forms (first defined at the site of Kot Diji in northern Sindh – Khan 1965) sometime around 2800 BC. There are a number of trenches in which Period 2 remains directly overlay natural soil, which indicates the settlement had expanded into new, previously unoccupied areas. Harappa was now clearly organized into two distinct mounds – AB and E. The latter included a portion of what

would become Mound ET. The size of the occupation during this phase is estimated to have been greater than 25 ha (Meadow and Kenoyer 2001: 24).

The cultural entity that residents of Harappa belonged to during Period 2 – the "Kot Diji" culture, extended far beyond the site and its immediate hinterland of the Punjab Plain (discussed in Chapter 2). Many have argued that "Kot Dijian" society represents an incipient stage of urbanization in northwestern South Asia just prior to the emergence of the Indus Civilization (Allchin and Allchin 1997; Durrani et al. 1995b; Flam 1981; Meadow and Kenoyer 2001; Mughal 1990a). Discoveries made during HARP excavations of Period 2 levels at Harappa have lent support to those assertions (Meadow and Kenoyer 1999, 2001: 23-26, 2005, *in press*). It now known that the massive city walls surrounding mounds AB and E had their origins in the Kot Diji Phase. Early Harappan revetment walls, although smaller than later ones, were built using mud-bricks fashioned in roughly the same dimensions (1:2:3 or 1:2:4 ratio) that would become the standard for bricks across the Indus Civilization. These structures would have served a variety of purposes (Belcher and Belcher 2000: 705; Meadow and Kenoyer 1994: 468) including helping to stabilize architecture, demarcating social and/or administrative boundaries, and providing protection against aggressors (human or animal) and seasonal flooding. Significantly, the construction of perimeter walls indicates that Kot Dijian Harappans had a concern for controlling access into their settlement. It also demonstrates that they had the ability to organize labor on the scale necessary to build and maintain monumental public works (Dales and Kenoyer 1992: 62). Emerging administrative sensibilities during this period are likewise suggested by the discovery of stamps seals and a standardized cubical stone weight – technologies indicative

of the need to document ownership, assess value and facilitate transactions in an increasingly complex socio-economic setting. The use of an early form of the Indus script by Kot Dijian residents of Harappa points to advancements in communication while the diversification of specialized craft industries is thought to be "linked to the emergence of a more highly differentiated society" (Meadow and Kenoyer 2005: 211). The wide variety of non-local raw materials recovered in Kot Diji levels points to active long-distance exchange, which was no doubt facilitated by the advent of bullock cart transportation (Kenoyer 2004). Faunal studies (Belcher 1991, 1998, 2003) have revealed that the importation of salted fish from the Arabian Sea coast (over 800 km distant) began during this period. All of these discoveries paint a picture of a settlement and a society that was markedly more complex than it had been during the Ravi Phase. When they are considered in relation to developments taking place on the regional level (discussed in Chapter 2) and those evident in the site's subsequent cultural phase (discussed next), a characterization of the Kot Diji Phase at Harappa as incipient urban is clearly appropriate.

Harappa Phase – Period 3 (2600 BC to 1900 BC)

In stratigraphic levels dating to around 2600 BC, ceramics and other artifacts characteristic of the Kot Diji phase underwent a "gradual transformation" into what is commonly thought of as the "Harappan" material culture assemblage of the Indus Civilization (Meadow and Kenoyer 2001: 25). This transition marked the beginning of the fully urban "Harappa" Phase (Period 3) at Harappa. The first constructions using baked-bricks appeared at this time and there was a "strong continuity in architectural orientation between the earlier city walls of Period 2 and the massive city walls of Period 3" (Meadow

and Kenoyer 2005: 224). At several excavated Indus Civilization sites in other regions such as Kot Diji in Sindh (Khan 1965), Nausharo in Balochistan (Jarrige 1989), Ghandi Umar Khan in the NWFP (Ihsan Ali *personal communication* 2004) and Kalibangan in Rajasthan (Thapar 1973), there are apparent localized discontinuities (burnt or sterile layers) between the remains of Early Harappan and Harappan Period occupations. This likely indicates that, not surprisingly, the emergence of the Indus Civilization occurred in different ways in different parts of northwestern South Asia. At Harappa in the Punjab, however, it is clear that the cultural roots of the site's Period 3 residents were local, emerging directly and without disruption from the preceding Kot Diji Phase.

The Indus Civilization existed for approximately 700 years. Although it exhibited a striking degree of diachronic continuity in terms of its general material culture attributes, this society underwent significant cultural developments during that time. At Harappa, these are evident as changes in site size, organization, architecture, artifact forms, motifs and technologies. Based on these documented developments and supported with ^{14}C dates, three chronological sub-periods of the Harappa Phase have been defined: *Period 3A* from 2600 to 2450 BC; *Period 3B* from 2450 to 2200 BC; and *Period 3C* from 2200 to 1900 BC.

Period 3A

Period 3A is the least well-understood of the Harappa Phase sub-periods due the fact that it is deeply buried. It has been possible to determine through deep soundings across the site that the area of occupation at this time remained more or less confined to mounds AB and E (Area J just south of Mound AB was *perhaps* also occupied by this time or soon after). The portion of mound E that during the Kot Diji Phase had extended short a

way into what would later become mound ET was truncated by the massive city walls built during Period 3A over the smaller ones of Period 2 (Meadow and Kenoyer 1997). Although the "Harappan" material culture assemblage was fully developed at this time, many aspects of it (ceramics, seals, writing, figurines etc.) would continue to undergo stylistic and functional changes as Period 3 progressed. Toward the end of this sub-period, the city, or at least certain parts of it, endured a period of "decay and disrepair" (Kenoyer 1991b: 55). Excavations of 3A levels on the south side of Mound E revealed clogged sewer drains that had overflowed into the streets, the remains of discarded animal carcasses and a general deterioration of the city wall and gateway (ibid.).

Period 3B

Period 3B appears to have been a time of significant renewal, growth and innovation at Harappa (Meadow and Kenoyer 2000: 337). The deteriorating architecture on the southern side of Mound E was rebuilt at the beginning of this sub-period (Meadow and Kenoyer 1997: 140) and at least two new habitation areas – Mound ET and Mound F, were incorporated into the settlement. Mound ET has been characterized as a "suburb" (Kenoyer 1998: 55) that grew directly east from Mound E. Around the beginning of Period 3B, the city wall of E was extended to encircle ET and a gateway was constructed at the southern juncture of the two mounds (Meadow and Kenoyer 1997: 143). The habitation area designated Mound F was built upon the remains of Period 3A garbage debris that had been dumped into a depression left by the mining of clay to build the walls and houses of Mound AB, which lay directly to the south (Meadow and Kenoyer 2005: 211-212). The massive wall surrounding Mound F and the large structure built within its confines called

the "granary" (although there is no real evidence that building served this purpose) were first constructed in Period 3B (Meadow and Kenoyer *in press*). Coinciding with this period of urban renewal and expansion are communication innovations in the form of tiny (≈ 1 cm in length) steatite "seals" (tablets) incised with the Indus script and small (≈ 2 to 3 cm) molded faience and terracotta tablets bearing writing and ritual scenes (Meadow and Kenoyer 2000).

Period 3C

Period 3C is the best studied of all the time periods at Harappa due to the fact that its extensive remains were made easily accessible when they were laid bare by brick-robbing activities. The most conspicuous and reliable material indicator of this sub-period is a distinctive type of ceramic known as a pointed-base goblet or "PBG." These mass-produced and evidently disposable drinking vessels are found in enormous quantities in every area of the site. When examining the records of past excavations at Harappa (for which stratigraphic control was generally poor), it is possible to be fairly confident that levels equivalent to Period 3C (or later disturbed deposits) are being reported when PBGs are mentioned or appear on a plan or section drawing. HARP excavators have determined that two other artifact types – rectangular steatite seals bearing the Indus script only and glazed faience geometric seals, were also used exclusively during this sub-period (Meadow and Kenoyer 2001: 27). Artifacts associated with the Bactria-Margiana Archaeological Complex (BMAC) of southern Central Asia likewise appear in the archaeological record at Harappa during Period 3C (Meadow 2002; Parpola 2005). The timing of these finds, which are both indicative of the cosmopolitan nature of the site and important evidence for

long-distance interaction with cultures originating to the northwest of the Indus Valley region, is wholly consistent with the established BMAC chronology (Hiebert 1994).

Each major mound at Harappa was settled by Period 3C, including the one over which the modern town of Harappa is built. In addition, remains have been encountered during past excavations, HARP operations (trenches, test pits, corings) and modern construction projects (sewers, wells, roads) away from the mounds that indicate the settled area during this period extended well beyond the parts of the site that are visible above the alluvial plain. Trenches sunk by M.S. Vats (1940: Chapter V) in Area G south of Mound ET revealed fragmentary structures and burials in association with numerous PBGs. Period 3C remains were also encountered during HARP excavations beneath the Mughal Period (ca. 16th century AD) caravansarai, which is situated just south of Mound E's southern gateway (Meadow and Kenoyer 1993: 14). The total area occupied during this sub-period is estimated to have been 150 ha or more (Dales and Kenoyer 1989a: 72).

Kenoyer hypothesized (1993: 186-187) that overcrowding during Period 3C may have led to "a breakdown of civic order" – at least in certain parts of the city. For example, the south side of Mound E was an active neighborhood at this time as indicated by extensive deposits filled with PBGs and numerous kinds of craft production debris. However, degrading architecture, construction re-using broken bricks, structures encroaching into public thoroughfares and clogged sewers point to a greatly diminished emphasis on civic maintenance (similar to that evident at the end of Period 3A) in this part of the city. In contrast, areas like Mound AB and Mound F were comparatively well-maintained during Period 3C and, based on a number of material indicators, are thought to

have been "inhabited by prosperous individuals" (Meadow and Kenoyer 2005: 212). Such diachronic fluctuations and synchronic disparities in the relative prosperity of different neighborhoods (zones, quarters, barrios, etc.) are typical of long-lived urban centers. Even so, the overcrowding and lack of civic control evident at Harappa during Period 3C, while not yet site-wide phenomena, may have been harbingers of things to come.

Transitional and Late Harappa Phases – Periods 4 & 5 (1900 BC to <1300 BC)

South Asia's first era of urbanization gradually began to come to an end around 1900 BC. For reasons not yet entirely understood, but which probably relate in some part to changes in river courses and a general demographic shift eastward (Possehl 1997b), the interaction networks that had culturally and economically integrated peoples across the Greater Indus region for seven hundred years diminished and several localized "Late Harappan" cultures emerged (discussed in Chapter 2). In the upper Indus Valley, the Late Harappan Period is represented by the "Cemetery H" culture. At Harappa, where it was first defined (Vats 1940: Chapter IV), this cultural phase is designated as Period 5 and seems to have been "firmly established" by 1700 BC (Meadow and Kenoyer 2005: 209). A transitional phase (Period 4) between the Harappa and the Cemetery H phases has been designated but is not well-defined temporally due to the poorly preserved nature of post-Period 3C deposits. However, excavations in the areas where small amounts of undisturbed strata from periods 4 and 5 remain (Trench 43 on Mound F and Trench 38 on Mound AB) seem to indicate that the transition did not involve the abandonment, invasion or destruction of the city. In fact, important continuities are evident. Many established architectural and craft traditions continue through the last two periods (Kenoyer 2005b) and

there are indications that users of "Late Harappan style pottery were living together with people using Harappan style pottery during the Period 4 transition" (Meadow and Kenoyer 2001: 34). Most significantly, the skeletal remains of Cemetery H Phase Harappans show "clear biological affinities with the earlier residents of Harappa" (Kennedy 2000: 312).

Continuities notwithstanding, the Late Harappa Phase represented a dramatic cultural transformation at Harappa (Kenoyer 2005b). Very different burial practices and new highly distinctive artifact styles and iconography are associated with the Cemetery H culture. The shell-working industry at the site seems to have come to an end (possibly due to the break down of long-distance trade routes to the south) while early glass-making technology and new innovations in bead-drilling appeared (ibid.). Barley became the dominant cereal crop (whereas wheat had been dominant in the Harappa Phase) and there was a large increase in the use of summer-cropped plants during the Late Harappan Period (Weber 1999, 2003). The need for the communication and administrative technologies such as the Indus script, cubical stone weights and stamp seals appears to have ceased despite indications that the site remained densely populated (Kenoyer 2005b). Judging by the distribution of Cemetery H ceramics on the site's surface and test pits made in the vicinity of Harappa town, it is estimated that an area up to 100 ha may have been occupied during Period 5. A terminal date for this phase at Harappa is, again because of the brick-robbing, difficult to estimate but it was most likely prior to 1300 BC (ibid.).

Because the total excavated area for periods 4 and 5 is so small (even more so than for Period 1), the rock and mineral artifacts recovered from these levels are treated as a single chronological sub-assemblage (Period 4/5) for the purposes of this dissertation.

Non-habitation areas at Harappa

I conclude this introduction to Harappa with a few brief remarks regarding areas of the site that were not inhabited. Nearly 7% of the rock and mineral artifacts recovered during HARP excavations and surface surveys came from such contexts.

An extensive cemetery area is located in the southwest corner of the site. A series of Late Harappan Period pot burials and graves were excavated in "Area H" (hence Cemetery H), immediately to the south of Mound AB and Area J (Vats 1940). Farther to the south is another group of interments in an area designated "R37." This Harappa Phase cemetery was the focus of HARP excavations during the late 1980s (Dales and Kenoyer 1989a) and several of the stone and metal artifacts that are the subjects of detailed geologic provenience studies are well-dated burial items associated with individuals in these graves.

A great deal of rock and mineral debris has been recovered from areas surrounding the site where Harappans dumped their garbage. One of the most extensive of these areas is known as the "Low Western" Mound, just off the southwest corner of Mound AB. Test pits sunk to natural soil there encountered no structures – only Harappa Phase refuse (Dales 1991: 187, 190). Nearby, a thick layer of Period 3C dump debris overlies Cemetery R37.

Although no artifacts have been recovered there, it is important to note the broad, flat, featureless area at the center of Harappa, which *may* be where a large water tank/reservoir (now filled in) was located (Kenoyer *personal communication*). Such water management structures have a long history in South Asia (Whitcombe 1982), going back as far as the Harappan Period at the sites of Dholavira (Bisht 2005) and Lothal (Leshnik 1968).

In the next section, I outline the three lines of inquiry pursued in this dissertation.

Three lines of inquiry

This research project was designed to shed light on the inter-regional relationships that residents of Harappa engaged in during the urban transformation of their settlement and society by identifying the geologic sources of the rock and mineral resources that they acquired. Provenience determinations, generated through both broad and fine-scale analyses of the site's stone and metal artifact assemblage and periodized with reference to the detailed chronological sequence presented in the previous section, are used to inform three lines of inquiry. The first two concern identifying the Harappans' inter-regional interaction/acquisition networks, defining their extent and tracking them through time. The third involves elucidating synchronic variations in those networks at the local or site level.

First line of inquiry – Harappan interaction/acquisition networks and their extent

There has been a great deal of speculation (which I review in upcoming chapters) regarding where it was that Indus Civilization peoples, their Early Harappan predecessors and Late Harappan successors obtained rock and mineral resources; who they came into contact with as a consequence; and the overall scope of those inter-regional trade activities. These issues constitute this dissertation's first line of inquiry, which asks: *With whom in the Greater Indus region or beyond were the residents of Harappa interacting (directly or indirectly) when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/resource acquisition networks during different periods in time?*

Much of this study rests on one assumption – that the acquisition of rock and mineral resources by residents of Harappa would have entailed either direct or indirect *interaction* with peoples dwelling in the regions from which such resources came. Stated another way,

it is considered to be highly unlikely that Harappans (or whoever was supplying them or supplying their suppliers) traveled into a region, obtained a resource and then left without having had any contact whatsoever with local populations. Although this seems almost self-evident, it is an assumption that needs to be declared at the outset. It is recognized that, like the issues of domination and the control of raw materials within source areas, actual face-to-face contacts between different individuals or groups in regions outside of Harappa cannot themselves be positively confirmed using the type of data produced for this study. Nevertheless, residents of Harappa will be said to have had interacted with the peoples of a particular geographic region when the material (rock or mineral) composing a stone or metal artifact excavated at the site is determined, through one of the methods outlined in Chapter 2, to have most likely been derived from a source in that region. This does not necessarily mean that site residents met or even had knowledge of peoples living in all source areas – only that they "interacted" with them through the transfer of material goods.

The avenues through which the stone and metal artifacts examined in this study came to Harappa will be called *acquisition networks*. The term "acquisition," as it is used here, is meant only to indicate that someone at the site *gained possession of* (acquired) a raw material or finished item at some point in time prior to it entering the archaeological record there. Acquisition may have occurred as "direct contact trade" between residents of Harappa and the peoples of a region where an artifact originated or as "indirect exchange" involving one or more (perhaps many more) intermediary groups (Lamberg-Karlovsky 1972; see also Renfrew and Bahn 1996: 352 for variations on those forms). The manner in which a stone or metal artifact was moved from Point "A" (source) to Point "Z" (Harappa),

the places it passed through along the way (points "B" through "Y") and the number of groups that were involved in the process is not determinable through provenience studies. What can be determined (with varying degrees of confidence and geographic precision) is the location of Point "A." That information enables us to infer *who* (which regional cultural phase) was most likely present at a rock or mineral acquisition network's point of origin.

As this dissertation proceeds, it is shown that, in some cases, the cultural phase associated with an acquisition network's point of origin is the same one to which residents of Harappa belonged (i.e., Ravi, Kot Dijian, Harappan or Cemetery H depending on the period). In other cases, it is a different Early Harappan phase or a non-Harappan phase. Still in other cases, the source of an artifact is determined to be located in an area where no archaeological remains contemporaneous to those at Harappa have yet been identified. When all such instances are considered for each of Harappa's chronological phases individually (as they are in Chapter 13), a series of detailed "pictures" of rock and mineral acquisition patterns emerge (Figures 13.2 through 13.7) that approximate the *extent* of its resident's inter-regional relationships at different periods in time. These synchronic pictures, although "Harappa-centric" (a feature mitigated somewhat by limited provenience data from other sites – Figure 13.8) and not necessarily representative of the full scope of interaction, can be used to examine general suppositions about culture contact and long-distance trade in northwestern South Asia during the late prehistoric period.

For example, it has been argued that Indus Civilization peoples, their predecessors and their successors had cultural connections and/or trade relationships with groups in various regions surrounding the Indus Valley such as (but not limited to) the highlands of

Balochistan (Fairservis 1975; Kakar 2002), the Subcontinent's mountainous north (Allchin 1984; Stacul 1985) and parts of Rajasthan (Agrawala and Kumar 1982; Hooja 1994; Misra 1995). The synchronic pictures of rock and mineral acquisition generated in this study indicate that Harappan connections/relations with peoples in some regions, especially those to the north of the Indus Valley, were stronger than is generally supposed. They also suggest that ties to other regions, notably Rajasthan, *may* have been less significant than previously thought.

Another issue to be examined concerns the extent to which rock and mineral resource acquisition networks were *internal* or *external* (designations discussed on pp. 79-81; see also Kenoyer 1991a: 358-361) to Harappan society. Some scholars feel that external trade with western Asia, in particular Mesopotamia, was a significant factor in the development of urban lifeways in the Greater Indus region (Asthana 1976; Possehl 1990; Ratnagar 2004). Others have argued that nearly all of the raw materials found at Harappan sites could have been acquired through internal networks and that the role of external trade in that regard has been overstated (Chakrabarti 1990; Lahiri 1990; Shaffer 1982). Still others argue that while the Indus Civilization was a product of indigenous developments, "once the urban phenomenon was established, external trade was a critical factor to the internal controls that maintained the Indus structure" (Kenoyer 1991a: 361). When the pictures of the full extent of rock and mineral acquisition are examined in Chapter 13, it is evident that, during all periods, some materials came from sources beyond the Greater Indus region. However, nearly all such sources were in areas directly adjacent to that region. So while it can be said that external trade for rock and mineral resources was a

constant feature at Harappa, there is no clear evidence, at present, indicating that acquisition networks extended to western Asia.

Finally, one of the most interesting and potentially important outcomes of this first line of inquiry involves what it reveals about regions for which the prehistoric period is, at present, poorly understood. As previously mentioned (p. 49), it will sometimes be the case that the point of origin (source) for a particular rock or mineral acquisition network is determined to be located in an area, such as the Hazara District of the NWFP, where no archaeological remains (Harappan or otherwise) contemporaneous to those at Harappa have yet been identified. That, of course, does not mean that the area surrounding the source was uninhabited. There are many parts of northwestern South Asia that have not been surveyed in detail or even at all. Moreover, sites in some regions may have been entirely lost to cultural and, especially in the tectonically active mountains of the northern Subcontinent, environmental processes. The only evidence that people were present in (or at least periodically visited) such areas during the Harappan Period might end up coming from studies such as this one. Knowledge of the extent of Harappan rock and mineral acquisition networks could allow us to "fill in the gaps" so to speak.

An issue that comes up repeatedly throughout this dissertation concerns the problem of Shortughaï – the previously discussed (p. 20) Harappan outpost in northern Afghanistan. At present, there are no other known Indus Civilization sites located between Shortughaï and Musa Khel, which is the next nearest Harappan settlement located 550 km to its southeast on the northern edge of the Punjab Plain. Traveling to and from northern Afghanistan would have necessitated that Harappans either go through or around the Hindu

Kush. Until now, there have been few indications as to which of the many possible routes (Chakrabarti 1990: 117-131; Channing 1885; Dale 1994: 46-55; Thomas and Knox 1994: 91-94; Markham 1879) they might have taken. However, if provenience determinations made for raw materials such as steatite (Chapter 7), vesuvianite-grossular (Chapter 9) and alabaster (Chapter 10) from Harappa and other Indus sites are indicative of the regions from which Harappans were accessing resources along the way, then some routes may have passed through what today is Pakistan's Northwest Frontier Province (Appendix 13.1).

Second line of inquiry – Diachronic changes in interaction/acquisition patterns

Questions in the second line of inquiry ask: *How did the patterns of inter-regional interaction/acquisition exhibited by residents of Harappa change over time?* The diachronic perspective necessary to address them is generated when the multiple synchronic pictures of Harappan rock and mineral acquisition produced for the first line of inquiry are regarded simultaneously. In Chapter 2, I present an overview of the culture phases that existed across northwestern South Asia from the early fourth through mid-second millennium BC. That, along with Harappa's own cultural sequence, provides the backdrop against which any evident diachronic changes (or lack thereof) in its resident's acquisition patterns are examined and, in Chapter 13, interpreted. Two ancillary queries related to changes in rock and mineral use and acquisition over time at Harappa are also outlined in this section.

Over the period of time (early third through mid-second millennium BC) that urban lifeways first emerged, existed and then waned in northwestern South Asia, the culture phase that residents of Harappa belonged to variously expanded, contracted, coalesced with other phases, split apart and shifted across the landscape (see Figure 2.6 on p. 80 for a

series of maps depicting these changes). Several questions relating to those societal and geographic transformations are taken up in the second, diachronic line of inquiry. To begin with: Did the Harappan's rock and mineral acquisition networks expand from the pre-urban Ravi Phase (Period 1), which currently appears to have been confined to the western Punjab, to the incipient urban Kot Diji Phase (Period 2), which extended approximately 1000 km from Sindh in the south to the Himalayan foothills in the north? Similarly, as the various regional pre/incipient urban Early Harappan culture phases coalesced into the Indus Civilization starting at around 2600 BC, did stone and metal artifacts from new sources reflecting the extra-regional scope of that urbanized society's internal interaction networks begin to appear in Harappa's assemblage? When the cultural horizons of site resident contracted (apparently) from regions to the north of the Indus Valley around that same time did their rock and mineral acquisition networks follow suit? Were acquisition patterns uniform throughout the urban phase (Period 3) at Harappa or did changes in their direction and extent occur during that long (≈ 700 years) period? Did a shift in the Harappan's acquisition networks accompany the dissolution of the Indus Civilization (ca. 1900 BC) and the eastward demographic movement of the Late Harappan Cemetery H culture phase?

Affirmative answers to some of the above questions will serve to support current views of inter-regional interaction and cultural development during South Asia's first period of urbanization. That is, some of the provenience data from Harappa provide new details that corroborate the sequence of extra-regional developments that scholars have previously defined through studies of settlement patterns, material culture affinities and other types of long-distance trade (the sequence and the studies are reviewed in Chapter 2).

For example, steatite and lead artifacts attributable to sources in the southern Balochistan region first appear at Harappa in levels dating to the site's urban phase (Period 3). This finding corresponds well with the established extra-regional sequence. The Early Harappan phases that residents of Harappa belonged to during periods 1 and 2 did not extend into southern Balochistan. It was not until Period 3 at Harappa that Indus Civilization peoples were present in that region at sites like Balakot and Bakkar Buthi and, presumably, had first-hand access to raw materials occurring there. The appearance at Harappa in Period 3 of steatite and lead from southern Balochistan sources is no doubt indicative of the extensive internal trade networks that had emerged by the Integration Era of the Indus Tradition[1].

Negative answers to some of the questions posed in this diachronic line of inquiry are also highly informative. For instance, the Early Harappan phase that Harappa's residents belonged to during Period 2 – the Kot Diji Phase, extended north across the Salt Range to the foothills of the Himalayas. Resources attributable to sources in those highland areas dominate the site's rock and mineral assemblage from that time. During the subsequent urban phase (Period 3 at Harappa), no Indus Civilization settlements (save for distant Shortughaï) have been found beyond the Salt Range, which creates the impression that Harappan interaction with previously occupied regions in the north diminished or ceased entirely. However, the diachronic picture of rock and mineral acquisition generated for this study suggests otherwise as the networks bringing stone and metal resources to Harappa from northern sources evidently continued unabated throughout the urban phase. Among the many implications of these findings (discussed in Chapter 13) is the possibility

[1] see definitions and descriptions on pp. 73 & 89

that there are undiscovered Harappan settlements in the north and/or that a "Late" Kot Diji Phase continued in that region concurrent with the Indus Civilization.

Two ancillary queries concerning diachronic changes

Two ancillary queries – one related to diachronic changes in the overall composition of Harappa's rock and mineral assemblage and the other to changes in the acquisition and use of heavy or *bulk* stone goods, are examined at appropriate points in this dissertation.

Diachronic changes in assemblage composition

Firstly, I evaluate the assertion by Dilip Chakrabarti (1998: 51) that, despite a marked intensification in craft specialization between the Early Harappan and Harappan periods in the Greater Indus region, there was "hardly any major change" in the types of raw materials used during those times. Is this characterization correct? At the outset of this project I thought perhaps it was not. It seemed reasonable to think that, because of the substantially larger geographic area encompassed by the Indus Civilization (as compared to the various Early Harappan societies) and its clear links to regions outside of South Asia such as Oman (Cleuziou 1992), consumers during the Harappan Period may well have had a wider variety of raw materials types available to them. Moreover, the development of new craft technologies during that period might have permitted some previously unusable types of raw materials to be exploited. A diachronic examination of the composition of Harappa's rock and mineral assemblage, which was fully inventoried and periodized for this study (Chapter 4), offered a good opportunity to test Chakrabarti's assertion. As it turns out, the basic suite of raw materials that was used at the site does appear to have been largely the same during both the Early Harappan and Harappan phases. Most (but not all)

discrepancies between the phases can be attributed to the lower probability of recovering less abundant rock and mineral varieties in earlier, less extensively excavated levels.

Diachronic changes in the acquisition and use of bulk stone goods

I have termed the largest and heaviest objects at Harappa *bulk* stone goods. By diachronically querying the record of where such goods were acquired and when certain varieties of them were used, it has been possible to examine emerging transportation capabilities and observe the appearance of what could be interpreted as a new expression of social status.

The vast majority (≈ 95%) of stone and metal artifacts recovered at Harappa are small in size and light in weight. Most weigh between a few milligrams up to a few hundred grams. Even though nearly all such artifacts probably first came to the site as part of larger, heavier pieces of raw material (unworked stones, roughouts or ingots) it is unlikely that the original pieces themselves weighed more than a few kilograms. There were doubtlessly some exceptions. Several very large chert flakes (see Figure 6.20 on p. 285) and cores have been recovered at Harappa that suggest heavy (perhaps up to 30 kg) chert nodules may have sometimes been transported to the site in whole or minimally reduced form. Of course, it is impossible to say with certainty that this was the case until at least one example is recovered. For this study, artifacts designated as bulk stone goods (≈ 5% of the assemblage) were those that weighed from one to 150 kilograms or are smaller fragments that were unquestionably once part of objects of that weight. With very few exceptions, such artifacts are either grindingstones (querns and mullers) or large-sized limestone objects such as ringstones.

The very largest bulk stone artifacts at Harappa do not even closely approach the weights of some of the monumental stones that were quarried and moved by other ancient societies (see Heizer 1966 for examples). Nevertheless, getting them to the site, which is hundreds of kilometers from any source, would have required, as compared to smaller varieties of stone, a significant expenditure of energy and specialized transportation capabilities. Of course, moving individual, heavy loads made up of many of smaller stones – say 20 kg bags of agate nodules – would have also required those things. However, because they were dispersed, it is impossible to know (without written records) exactly how heavy were there single shipments of small-sized raw materials actually. In contrast, the sandstone from which a 20 kg quern was fashioned clearly could have weighed no less than 20 kg when it was conveyed to Harappa. This is the unique feature of bulk stones. Although it is hard to quantify, some degree of expense/value can be confidently associated with even the most mundane of such goods because of their weight and the difficulty inherent in moving them.

By focusing on factors of weight/size and distance/direction to sources, it was possible to diachronically query the records of the two main types of bulk stone goods at Harappa. In Chapter 5, I argue that the trend away from the acquisition of querns and mullers from relatively nearby occurrences of poor quality stone toward more distant sources of higher quality material is due, in part, to the advent of new technologies (i.e., wheeled transport) that facilitated the long-distance transportation of heavy bulk goods. In Chapter 11, I tentatively interpret the finding that non-utilitarian bulk-sized limestone objects (some weighing over 100 kg from sources over 800 km away) were used only

during latter part of urban phase to reflect a new development in the way that certain Harappans expressed their social status through the consumption and display of stone.

Third line of inquiry – Site-wise synchronic variations

Earlier (p. 15) I discussed Kenoyer's thesis (2000) that those groups who ruled Indus Civilization cities acquired and maintained their power to do so, in part, by controlling essential raw materials as well as the manufacture and distribution of status-defining items. Kenoyer argued (ibid.: 89-90) that extensive inter-regional interaction networks in combination with the wide distribution and multiple occurrences of essential resources across northwestern South Asia "stimulated economic competition and more complex economic and political interaction between the early village communities" of the ancient Indus Valley. Economic power and political authority, rather than being concentrated in a single individual, institution or community, instead came to be distributed among multiple groups of competing elites. By the urban phase this was reflected in the segregated layout of Indus Civilization cities. The multiple walled and gated areas at settlements like Harappa and Mohenjo-daro are thought to have been "centers of power" where competing elites not only dwelled but also controlled access to valuable resources and the production/distribution of the wealth and status-defining items made from them (Kenoyer 1997a: 69). It is these issues – competition and the control of essential rock and mineral resources, which are the focus of this dissertation's third line of inquiry: *Did synchronic variations in patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

The expectations are fairly straightforward. If the major mounds at Harappa (recall Figure 1.4) were inhabited by separate communities which were ruled by elites actively competing with one another through the control of essential resources and goods, then synchronic variations in the material variety and/or geologic provenience composition of the site's rock and mineral artifact assemblage *might* be observable. For example, if it is determined that a specific material variety was used only (or mainly) on a particular mound, then this could be construed as evidence that the inhabitants/rulers of that mound closely controlled access to that material. Similarly, if it is found that communities on different mounds were utilizing the same variety of rock or mineral but from different geologic sources, then this could be viewed as evidence for competition between the elites who presumably controlled the raw materials coming into those areas.

Ultimately, phase-by-phase synchronic assessments of Harappa's rock and mineral assemblage revealed both striking similarities and some notable differences among its mounded areas. Overall, it appears that, during all periods, Harappans living and working in different parts of the site had access to and were acquiring raw materials and/or finished goods derived from the same geologic sources. The two biggest exceptions are for vesuvianite-grossular and "Ernestite," which appear to have been almost exclusively used by Harappans dwelling on mounds E and ET.

Chapter conclusion – Dissertation outline

In this introductory chapter I have presented the principal research objective, the general background to the Indus Civilization; a discussion of theoretical orientation, a review of Harappa's cultural/chorological sequence and an outline of the three lines of

inquiry pursued in this dissertation. In Chapter 2, the site of Harappa is placed into its geographic, geologic and ancient temporal-cultural contexts within the Greater Indus region. In Chapter 3, the various research strategies and methods employed in this dissertation are discussed. In Chapter 4, the 56,350 rock and mineral artifacts that have been recovered from Harappa to date are categorized, periodized and quantified. Then, over the next eight chapters, approximately 3000 of those artifacts representing eight main material varieties are subjected to geologic provenience analysis using one (or more) of the methods described in Chapter 2. I begin with a complete analysis of Harappa's grindingstone assemblage (Chapter 5) and then move on to geologic provenience studies of judiciously selected samples from the assemblages of chert (Chapter 6), steatite (Chapter 7), agate (Chapter 8), vesuvianite-grossular garnet (Chapter 9), alabaster (Chapter 10), limestone (Chapter11) and various metals (Chapter 12). In the end, specific provenience determinations (a source or source area in defined geographic space) were made for 2170 artifacts from Harappa and 119 artifacts from other sites. These data are summarized in Chapter 13, brought to bear on the three lines of inquiry outlined in this chapter, and the implications of the answer to those inquiries are discussed. Brief concluding remarks including thoughts for future studies are presented in Chapter 14.

Chapter 2

Harappa in context

Chapter 2 – Harappa in context

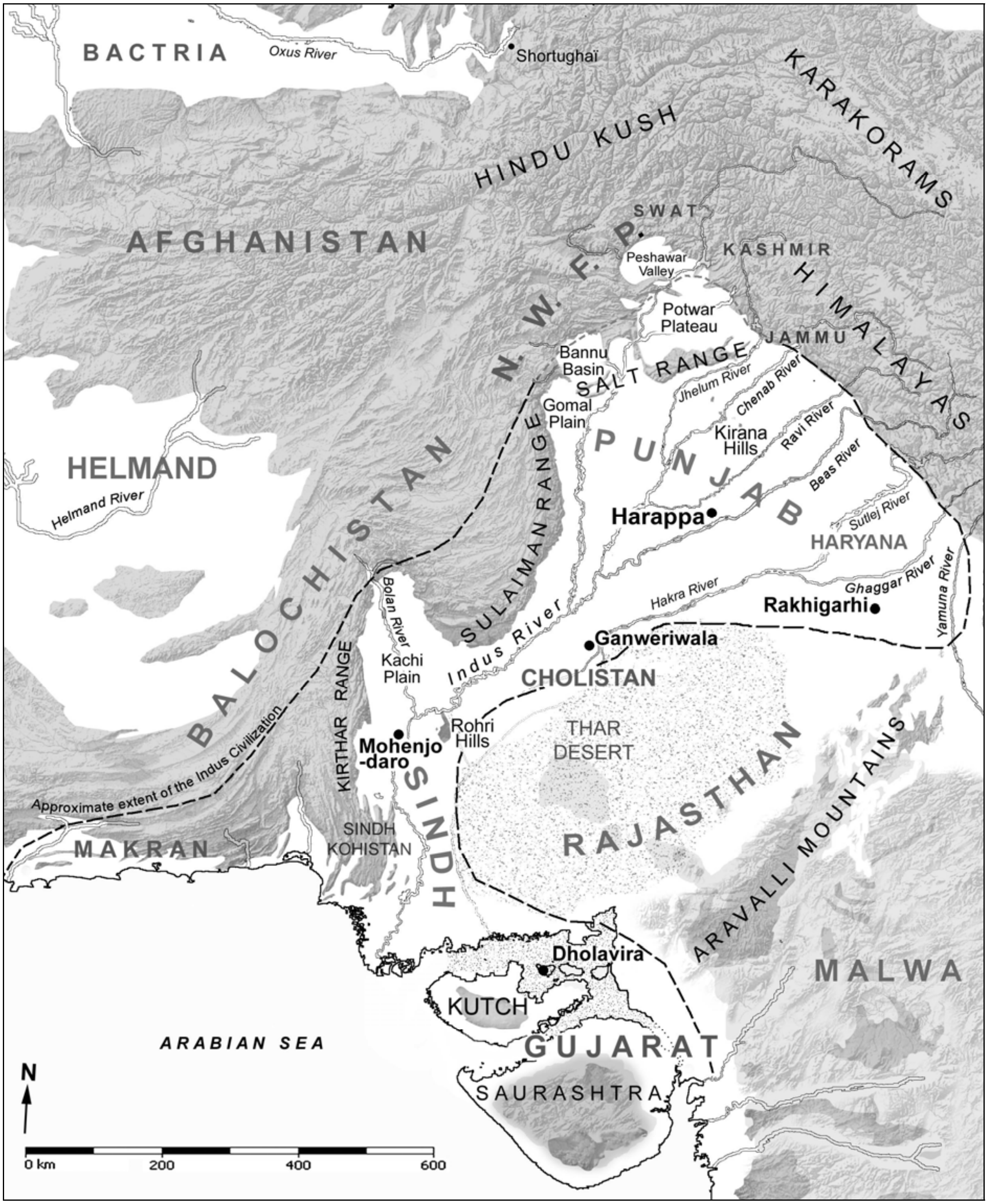
Chapter introduction – The Greater Indus region

The Indus Civilization, at its greatest extent during the latter half of the third millennium BC (Figure 2.1), is variously estimated to have covered an area of northwestern South Asia ranging from 680,000 (Kenoyer 1991a: 352) to 1,000,000 square kilometers (Jansen 2002: 105). Many Indus settlements are located in geographic regions well beyond the river valley that is its namesake. This prompted Rafique Mughal to propose (1970) the term *Greater Indus Valley* as a way to refer to the broader region that the civilization encompassed. The purpose of this chapter is to situate the focal point of this dissertation – the site of Harappa, into the geographic, geologic and ancient temporal-cultural contexts of the Greater Indus* region (for brevity and consistency I hereafter drop **Valley* from the term).

Geographic context

Harappa is located at N 30º 37′ 31″, E 72º 51′ 52″ in District Sahiwal, Punjab Province, Pakistan. From that geographic vantage point in the center of the Punjab Plain near the Ravi River, the site was well placed in terms of access to resource zones both within and immediately surrounding the plain. It is also well situated in terms of other Indus settlements and large urban centers where rock and mineral resources from more distant areas could probably be indirectly obtained. In this section, I provide a brief and general overview of the major geographic features and regions of the Greater Indus region (Figure 2.1) and the principal routes through which residents of Harappa may have interacted with Indus peoples or other cultures living across this broad area. Much greater detail on pertinent features and regions are provided in upcoming sections and chapters.

Figure 2.1: Map showing approximate extent (dashed line) of the Indus Civilization, its five main cities and the major regions and features of the Greater Indus region.



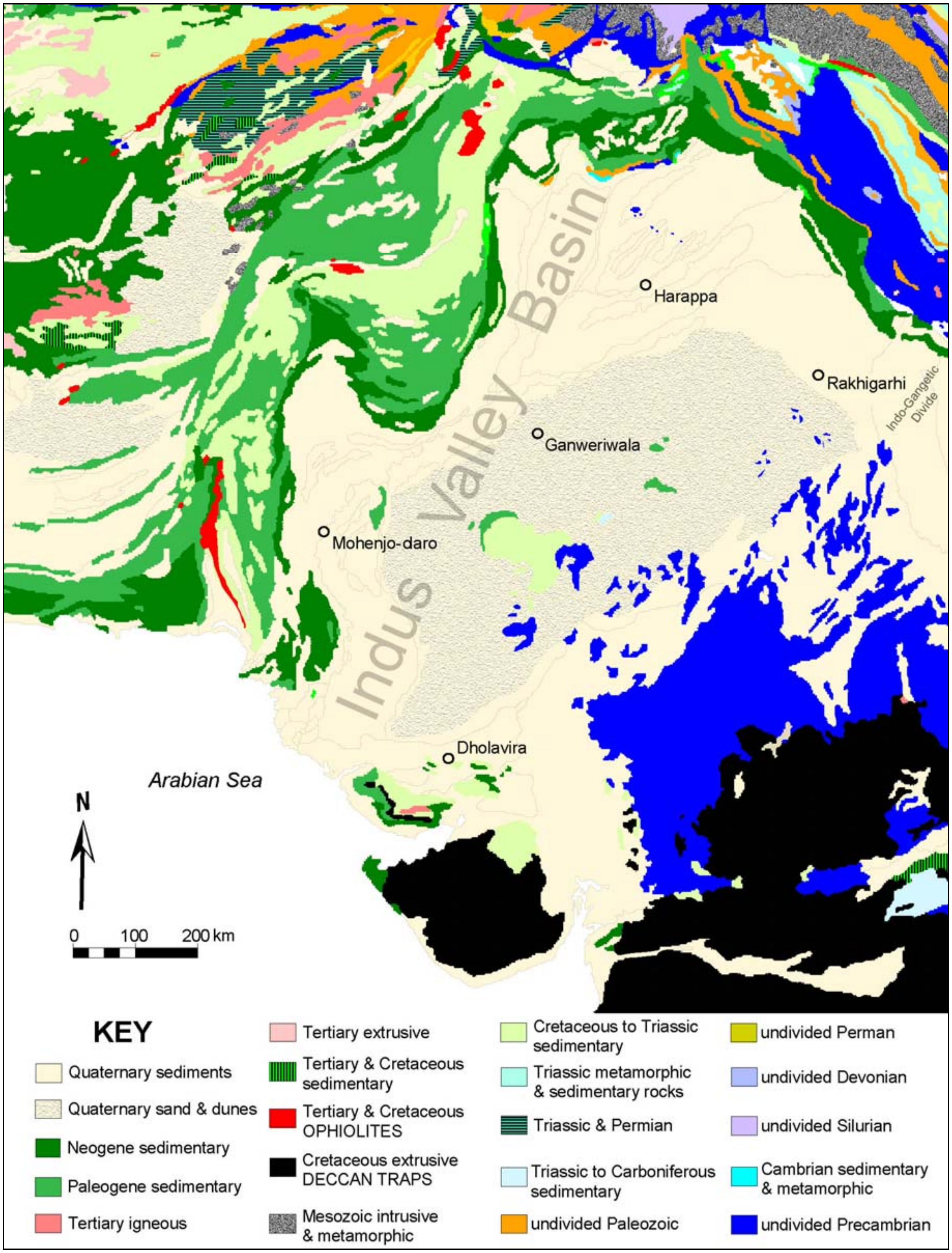
The Kirana Hills – a series of rocky outcrops 120 km north-northwest of Harappa, are the first and only features in the general vicinity of the site that rise above the flat expanse of the Punjab Plain. On the plain's western margin, 220 km from Harappa, the north-to-south running Sulaiman Mountains begin and from there numerous passes lead up into the highlands of northern Balochistan and from there to Afghanistan and the Helmand Basin. Moving northward, the next closest major features are the Gomal Plain, which is essentially a trans-Indus River extension of the upper Indus Basin alluvial plains and the Salt Range. From there low passes lead north into the Bannu Basin and Potwar Plateau. The most direct routes to the distant Indus Civilization outpost of Shortughaï, located in far northern Afghanistan, would have passed through these regions. Continuing clockwise, Harappans would have needed only to follow the rivers of the Punjab northeast as they passed through Jammu, Kashmir and into the western Himalaya in order to access the rich resources of those regions. Lying east of Harappa are the Indus settlements of the eastern Punjab and Haryana plains including the large urban center of Rakhigarhi, which might have provided indirect access to the resources of the northern Aravalli Mountains as well as the central Himalaya. To the south-southwest of Harappa, the Indus city of Ganweriwala and other related sites along the now dry Ghaggar-Hakra River system are points where interaction with ancient desert nomads in the Cholistan region (Mughal 1994b) who might have had access to the resources of western Rajasthan. The Ghaggar-Hakra and the parallel-running Indus River would have been the main southward routes from Cholistan and the Punjab toward the Sindh region and Mohenjo-daro, the largest Indus city. Raw materials from the Rohri Hills, the Kirthar Range, Sindh Kohistan and southern

Balochistan may have passed northward to Harappa along these same riverine routes. From northern Sindh, it would have been possible to follow the Bolan River through the Kachi Plain and into the highlands of central Balochistan. Finally, from southern Sindh, a Harappan trader may have the traveled westward to Indus settlements and outposts in the Makran region or continued south to Gujarat and the Indus city of Dholavira.

Geologic context

In relation to the geology of the Greater Indus region (Figure 2.2), Harappa simply could not be more optimally located for provenience studies of its rock and mineral artifacts. The region is dominated by an immense (approximately 1200 km long by 600 km wide at its greatest extents) bowl-like depression, called the *Indus Valley Basin* (or simply Indus Basin), which is filled with alluvial sediments. Harappa is located upon the upper portion of this basin ("upper Indus Basin") and, with the exception alluvial clays and sands, there are no rock or mineral resources whatsoever to be had within a minimum distance of 120 km of the site. This situation is a boon rather than a hindrance to provenience studies. There is no need to attempt to determine what stone or metal resources found at the site are local and what are not because none of them are. All lithic artifacts at Harappa had to have come from one of the many, highly varied (another big positive in terms of provenience studies) geologic formations within or surrounding the alluvial plain (itself a geologic formation) of the Indus Basin. Here, I collectively refer to those non-alluvial formations as the "highlands," although some are merely very low hills or outcrops that barely rise above the plains. In this section, the general geology of the Greater Indus region is discussed in terms of its alluvial plains and highlands.

Figure 2.2: General geologic map of the Greater Indus region (adapted and simplified from Wandrey and Law 1998 - USGS Open-File Report 97-470C)



In this section and at various points throughout this dissertation, I refer to geologic formations using terms that designate their relative chronological age (geologic Eras, Periods and Epochs). In certain instances, I also provide absolute dates. For those times that I do not, a geologic timescale (Appendix 2.1) has been provided for reference.

The Alluvial Plains

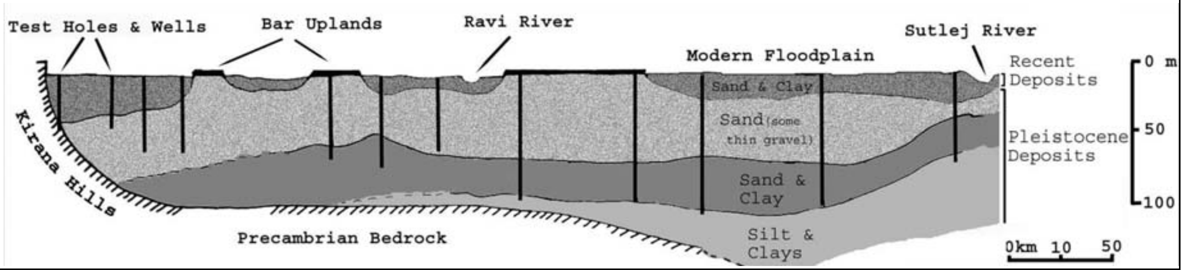
The physical character of the Indus Basin alluvial plain is a product of the many rivers and streams that flow through it, as well as various tectonic and aeolian processes (Beg 1993; Flam 1993b). Throughout the Pleistocene and Holocene epochs, its major watercourses have migrated to new locations, been captured by other rivers or have disappeared entirely (Oldham 1887; Roonwal 1968; Thussu 1999). The rivers on the maps used throughout this dissertation are based on what their courses *may* have looked like around 2000 BC (Wilhelmy 1969). It is still not clear as to whether or not the now dry Ghaggar-Hakra-Nara system ever flowed to the sea (Flam 1993b; Possehl 1998a) so its possible course through the Sindh region is marked as a dashed line on those maps. The actions of the Indus and other rivers flowing through the basin have resulted in the formation of a variety of alluvial features including floodplains, terraces, meander scars, oxbow lakes and tablelands (see Belcher and Belcher 2000, Pendall and Amundson 1990 and Schuldenrein 2002 for detailed geoarchaeological accounts of these features). The high areas between major rivers are known as *doabs* or *bar uplands* and rise as much as 15 meters above the flood plains (Bender 1995c: 300). Although the climate of the Indus Basin plains is generally arid, its fertile alluvial soils combined with winter rains and summer monsoons create the potential for abundant harvests (Weber 2003: 176).

Harappa lies in the center of the broadest portion of the upper Indus Basin alluvial plain, an area known as the *Punjab*. The name "Punjab" literally means the "land of the five rivers" – *panj* (five) *ab* (waters). Traditionally, this refers to the region watered by the Jhelum, Chenab, Ravi, Beas and Sutlej rivers. Physically (and, during various periods, politically) the Punjab has been defined as inclusive of most or all of the alluvial lands comprising the upper portion of the Indus Basin (Figure 2.2) – from the Sulaiman Range in the west to the Indo-Gangetic divide in the east and from the Salt Range and Himalayas in the north to Sindh and the deserts of Rajasthan in the south (Government of Great Britain - India Office 1908: 245-46). The designation "Punjab Plain" as used in this dissertation refers to this larger region.

The physical landscape of the plain clearly influenced settlement patterns in the Punjab and elsewhere. Proto-historic sites discovered in the Punjab tend to be located on or near the edges of the doabs (Schuldenrein et al. 2004: 779). Such settings would presumably have provided early agriculturalists access to the fertile and well-watered lands of the flood plains while generally keeping their villages above the normal annual flood levels. These locations would have also been situated along important riverine transportation and communication routes.

In terms of the present study, it is of utmost importance to note that the alluvium of the Punjab Plain has been accumulating since at least the early Pleistocene and it is, therefore, extremely deep (Kazmi and Jan 1997: 267). Cross-sections based on tube well logs (Figure 2.3) indicate that, in some places, depths of 100 m or more (in places much more) exist before Precambrian bedrock is reached. With the exception of sporadic and

Figure 2.3: Cross section of the Punjab Plain looking northeast from Harappa (after Kazmi 1995c: Fig. 3.14 C)



deeply buried thin beds of gravel (ibid.), pedogenic carbonate nodules or *kankar* (Amundson and Pendall 1991: 18) and subsurface formations of gypsite in the deserts of Rajasthan and Cholistan (Joshi 2000; Ahmad 1969: 92), the alluvial strata of the upper Indus Basin is composed solely of sand, silt, clay and loess for no less than 120 km surrounding Harappa. Every rock and mineral object recovered at the site, from the tiniest pebble to the largest quern, had to have been purposefully transported there by some human agent(s). Therefore, all stone or metal artifacts can potentially provide information about the interaction networks that linked Harappa to various rock and mineral sources in the outcrops, hills and mountains (highlands) within and surrounding the Indus Basin.

The Highlands

The highly varied nature of rock and mineral assemblage at Harappa (Chapter 4) is a reflection, at least in part, of the diverse geologic sources that residents of the site had access to in the highlands of the Greater Indus region (Figure 2.2). The Indian subcontinent's collision with the Asian Plate beginning approximately 55 million years ago (Powell 1979: 16) is the ultimate source of this diversity. Enormous beds of sedimentary detrital rock (sandstone and shale), carbonates (limestone and dolomite) and sulfide evaporates (gypsum and anhydrite) developed in the shallow Tethys Sea that existed prior

to and during the convergence of the two continental plates (Bender 1995a: 11–13). As the Indian Plate subducted beneath Asia, these beds were folded, raised and exposed in massive sequences along the northern and western margins of the Indus Basin (Farah et al. 1984: 161–163). Another product of this subduction was the development of volcanic island arcs and their associated rocks (basalt, rhyolite, andesite, etc.), which eventually were emplaced between the sutured continental margins (Shams 1995a: 131–133). Similarly, large fragments of oceanic crust (*ophiolites* – composed of ultramafic rocks and containing radiolarian cherts) were obducted onto the continental crust (Asrarullah and Abbas 1979). Pressure and stress from the collision altered existing geologic formations in myriad ways and brought to the surface highly metamorphosed rock from as deep as the earth's mantle (Shams 1995a). East of the Indus Basin, one of the oldest portions of the earth's crust, the Indian basement complex, rose in the form of the Aravalli Mountains. Rich deposits of base metals and metamorphic minerals can be found across the length of that range (Wadia 1975: 94–95). Finally, a wide variety of agate, carnelian and other microcrystalline silicate geodes eroded from the basalts of the Deccan Traps that extend into the Gujarat region southeast of the Indus Valley (Merh 1995: 166-167).

Several scholars have argued that ancient Indus Tradition peoples likely acquired certain varieties of rocks and minerals from the beds of rivers flowing from the mountain ranges surrounding of the Indus Basin, thus making it unnecessary for them to have traveled to in situ geologic formation containing of those materials (Inizan and Lechevallier 1990: 51–52; Kenoyer 1998: 35; Khan et al. 1988: 102). And for certain materials this is indeed, to some extent, true. However, it would be a mistake to think of riverbeds or the

alluvial fans at the base of mountain ranges as cornucopias containing all of the types of stone found in the formations that they drain. River-borne sediments undergo rapid fining through abrasion, chipping, splitting, cracking and chemical weathering as they are moved downstream (Werrity 1992). Tough rocks such as granite, limestone and sandstone have slower attrition rates than softer materials that are easily fractured (ibid.: 343). A resident of Harappa seeking a sandstone grindingstone would have needed only to travel to one of the massive alluvial fans at the base of the Sulaiman Range to get a suitable cobble rather than into the mountains themselves. However, to obtain a material like chert, which easily becomes chipped and fractured as it is carried downstream, or steatite, which quickly disintegrates, it was probably necessary to travel to the actual source or, at least, very close to it. Although further studies are needed, preliminary observations of the movement of radiolarian chert down the Tochi River from its source in the Barzai region of Waziristan indicate that this material becomes highly fractured and rare at the point the river nears prehistoric sites on the Bannu Basin plain, such as Lewan (Allchin and Allchin 1993), some 70 or so kilometers downstream (*personal observations* 2001). Similar examinations were made of drainages in central Balochistan, confirming Inizan and Lechevallier's observations (1990: 52) that good quality chert in Bolan River near Mehrgarh is actually quite scarce. It is certainly possible that slope gradient and river discharge may have changed since prehistoric times, thus altering and/or obscuring the composition of drainages that once contained good quality material. However, it is much more likely that then, as now, someone needed to travel directly to source deposits in order to obtain most of the varieties of rocks and minerals found at Harappa.

Temporal-cultural contexts

Jim Shaffer noted (1982: 192) that "with the exception of turquoise and lapis lazuli" all raw materials used to make the objects found at Indus Civilization sites occur "*within* the distribution area of the Harappan culture in the Greater Indus Valley" [italics added]. This is true, more or less, for most types of stone or metal used at Harappa during the urban phase and is demonstrated on a material-by-material basis in the next chapter. However, many of those artifacts were deposited when people dwelling at the site were not members of an urbanized society as extensive as the Indus (Harappan) Civilization. Both prior to and following the urban phase (Period 3) at Harappa, there were numerous varieties of raw material for which all potential sources would be considered "external" (*a la* Gupta 1984; Kenoyer 1991a: 358-61) to the larger regional society/culture that the site's residents belonged to during those periods of time. In order to evaluate diachronic change in the extent of the inter-regional interaction networks that Harappans participated in, it is necessary to 1) provide a temporal framework (one broader than the site's chronology, which was outlined in Chapter 1) with which to examine those networks in an extra-regional context and 2) to situate Harappa (its residents and rock and mineral assemblage) in relation to its regional and extra-regional cultural contexts.

Traditions, eras and phases

In this dissertation, I follow the chronological framework for ancient South Asia that Jim Shaffer (1992) adapted from a system originally developed by Willey and Phillips (1958) for New World archaeology. Underlying this framework are the concepts of *traditions, eras* and *phases*.

A "tradition" is a "persistent configuration of technologies and cultural systems within a context of temporal and geographic continuity" (Shaffer 1992: 442). Although an often highly diverse range of human adaptations existing over long spans of time may be encompassed within a tradition, they are all broadly related and collectively distinct from those of groups belonging to other traditions. Along with the *Indus (Valley) Tradition*, which may be thought of as the milieu of cultural/technological adaptations in the Greater Indus region within which urbanized civilization eventually emerged and existed, Shaffer defined (ibid.) the *Balochistan* and *Helmand* traditions to encompass concurrent but distinct cultural developments in those two regions west of the Indus Valley. Using Shaffer's framework, Kenoyer (1991a, *in press* b) has further defined several other traditions contemporaneous to that of the Greater Indus region: the Ganga-Vindhya Tradition (Ganges Basin and Vindhya region), the Malwa-Rajasthan Tradition (Aravalli Range region and Malwa Plateau) and the Bactria-Margiana Tradition (southern Central Asia).

Traditions are sub-divided into *eras* and *phases* (Shaffer 1992). Figure 2.4 is table showing those for the Indus Tradition. "Eras" are descriptive units in which cultural "phases" (below) are grouped based on their general attributes (such as basic subsistence economy) and differing degrees of interaction/integration. They are non-evolutionary and do not have set temporal or geographic boundaries. Several may exist concurrently in a tradition (e.g., Indus Tradition Foraging era groups co-existed with Regionalization era communities up until the Integration era) or even be absent entirely (some traditions, for instance, do not experience Integration and Localization eras). Eras are made up of "phases," which are defined on the basis of a set of distinctive material culture traits

(frequently this is a diagnostic assemblage of ceramics) present in a specific place and time. They are of short duration as compared to traditions and eras but may encompass a geographic area ranging from that of a single site to an entire culture tradition. Site specific chronologies, such as that for Harappa (Figure 2.4 third column), intersect with certain phases and may cut across multiple eras and even traditions.

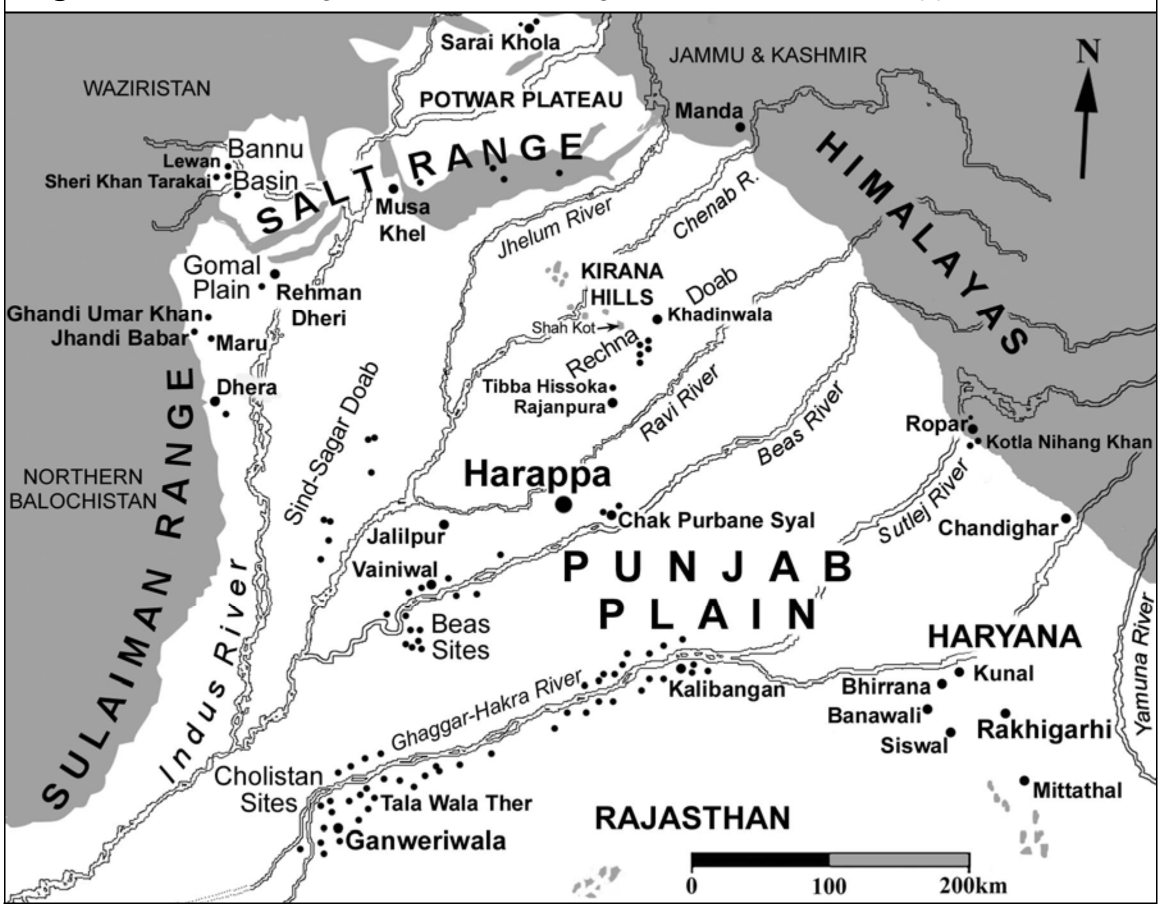
Figure 2.4: Eras and phases of the **Indus Tradition**
(modified from Belcher 1998; Kenoyer 1991a and *in press* b; Shaffer 1992)

Eras "Text" (Shaffer 1992: 442)	**Phases**	***Harappa*** *see Figure 1.6 for dates*
Foraging Era *ca. 10,000 to 2000 BC*	Mesolithic and Microlithic	
Early Food Producing Era *ca. 7000 to 5000 BC* "Economy based on food production and the absence of ceramics"	Mehrgarh Phase	
Regionalization Era *ca. 5000 to 2600 BC* "Distinct artifacts styles, essentially, ceramics, which cluster in time and space and interaction networks which link dispersed groups"	**Early Harappan Phases** Hakra Phase SKT/Tochi-Gomal Phases Balakot Phase Ravi Phase Kot Diji Phase Sothi-Siswal Phase Amri Phase	Ravi Phase – Period 1 Kot Diji Phase – Period 2
Integration Era *ca. 2600 to 1900 BC* "Pronounced homogeneity in material culture distributed over a large area reflecting an intense level of interaction"	**Harappan Phase** *Indus Civilization* Late-Kot Diji Kulli Sorath	Harappa Phase – Period 3A Harappa Phase – Period 3B Harappa Phase – Period 3C
Localization Era *ca. 1900 to 1300 BC* "Comparable to regionalization except that there is a more generalized similarity in artifact styles, indicating continued, but altered, presence of interaction networks"	**Late Harappan Phases** Punjab (Cemetery H) Jhukar Rangpur	Harappa/Late Harappa *Transitional* Phase – Period 4 Cemetery H Phase – Period 5

Ancient settlements of the upper Indus Basin

Our understanding of the ancient "cultural landscapes" (Sauer 1925) in which Indus Civilization cities developed and existed has grown tremendously since the original excavations of Harappa and Mohenjo-daro. Possehl provides a comprehensive account of the many expeditions and surveys that have been conducted in the Indus Valley and the regions surrounding it in his 1999 book *Indus Age: The Beginnings*. In this section, I focus primarily on the discovery of ancient sites in the upper Indus Basin region (Figure 2.5). These settlements constituted Harappa's cultural hinterland and provided the links across the vast alluvial plain of the Punjab to rock and mineral source areas in the highlands.

Figure 2.5: Select Regionalization and Integration Era sites of the Upper Indus Basin



At that time it was originally excavated, Harappa was one of only three Indus Civilization settlements known to exist in the entire upper Indus Basin region, the others being a small mound called Chak Purbane Syal 27 km away and another called Kotla Nihang Khan 350 km away on the eastern edge of the Punjab Plain (Vats 1940: Chapter XIX). Eventually, however, many more prehistoric sites (not all of them of them Indus Civilization settlements) were discovered through reconnaissance and survey. The bulk of these were found along the drainage of the now dry Ghaggar-Hakra River (Stein 1942; Mughal 1997). Many were also identified on the plains of the eastern Punjab and Haryana (Bhan and Shaffer 1978; Joshi and Bala 1993). In Pakistan, clusters of sites were found along the margins of the upper Indus Basin on the Gomal Plain (Dani 1971), Bannu Basin (Khan et al. 1988) and Potwar Plateau (Halim 1972). Yet during that time few sites, with the notable exception of Jalilpur (Mughal 1974b) and Vainiwal (Mughal 1972b), were found in the western Punjab in the general vicinity of Harappa. For decades the site seemed to "exist in a near vacuum" (Fentress 1982: 254). The apparent absence of Indus Civilization settlements between Harappa and the Salt Range led Possehl (1984) to hypothesize that the region at that time may have largely been the domain of ancient pastoralists who had little impact archaeologically upon the landscape. Even as late as the 1990s it seemed to some scholars unlikely that a significant number of sites would ever be discovered on the plains of the western Punjab region (Chakrabarti 1995: 36).

Fortunately, the preliminary results of recent surveys directed by the Department of Archaeology and Museums, Government of Pakistan (Mughal et al. 1996) and others have begun to fill gaps in our knowledge regarding the prehistoric cultural landscape of the

western Punjab Plain. Around 40 sites, ranging in age from the early to mid-fourth to the mid-second millennium BC, have been located in the area between the Sutlej and Indus rivers. Eighteen were discovered south along the old bed of the Beas River (Wright et al 2002; Schuldenrein et al. 2004). Nine were found in the doab (called the Rechna doab or Sandal Bar) between the Ravi and Chenab rivers (Dar 1983, Qasim 2002; Dogar *in press*). Seven were located around 125 km west of Harappa in the southern Sind-Sagar (Indus-Jhelum) doab (Mughal et al. 1996: 111-12). Several others have recently been identified in the Salt Range (Dar 2002) and, although not plains settlements, have helped to bridge what once was a significant cultural void between prehistoric settlements in the Punjab and the distant group of Early Harappan sites clustered around Sarai Khola on the northern Potwar Plateau (Halim 1972). These discoveries in a region once thought to be largely devoid of settlements are a good indication that there may be "many more sites in the Punjab waiting to be documented" (Mughal 1990a: 184).

The northern part of the Punjab Plain (from the Salt Range to the Chenab River) is one area that still awaits survey. At the end of the 19^{th} century the archaeological remains of this region were described in the *Gazetteer of the Shahpur District*:

> In the Bár tract between the valleys of the Chenáb and Jhelum rivers there are some 270 mounds of earth mixed with loose bricks and fragments of pottery which mark the sites of former towns and villages. It is unlikely that those sites were inhabited at any one time. More probably they were built upon when the rivers flowed in one or other of the old channels still existing in the Bár (Wilson 1897: 30-31).

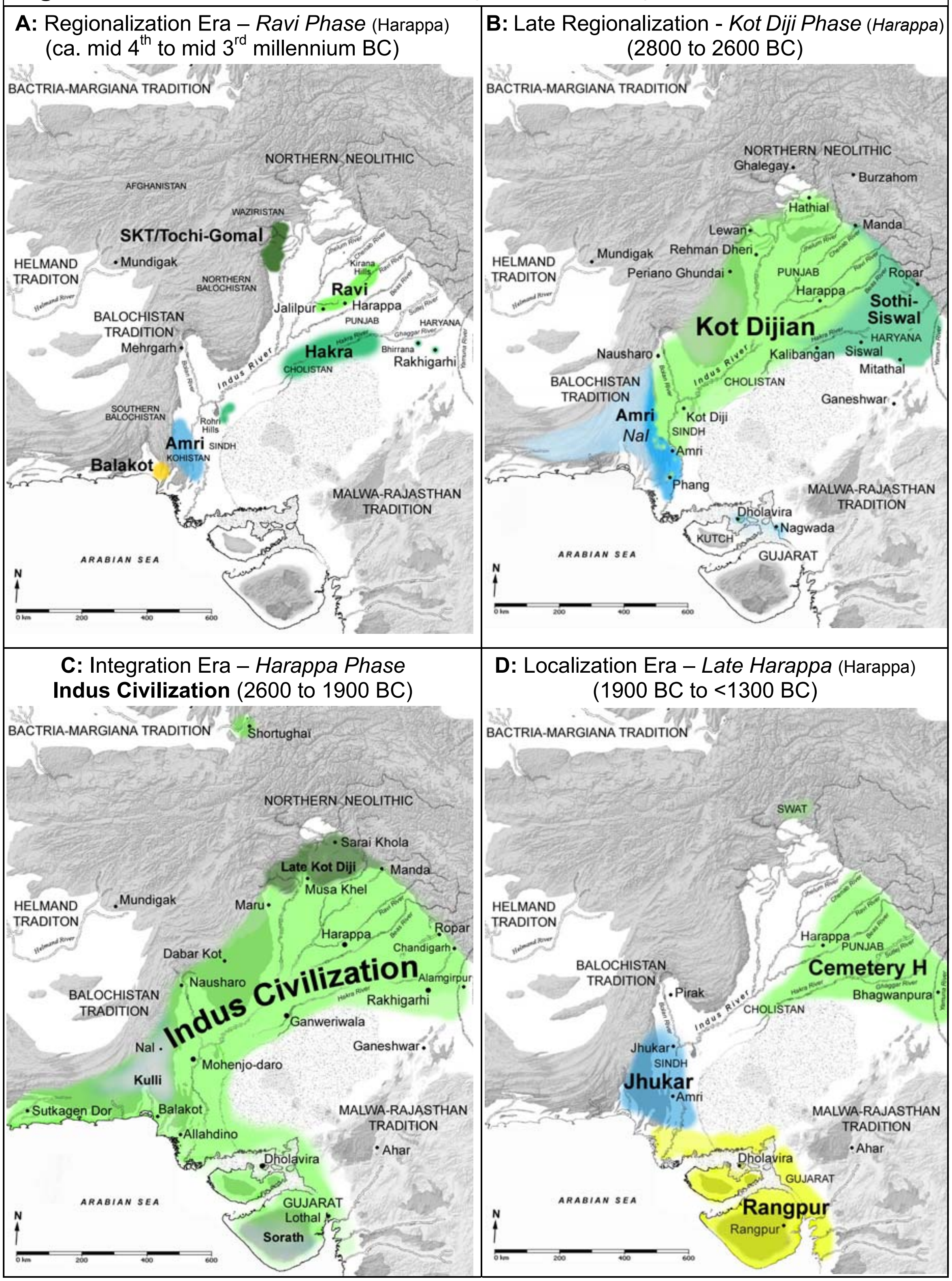
The above description is, in a way, reminiscent of the Cholistan desert region on the southern fringe of the upper Indus Basin. There, hundreds of prehistoric sites belonging to various phases are located along the numerous dry river beds marking where the Ghaggar-Hakra flowed at different points in time as it migrated across its former floodplain (Mughal 1997). If the density of prehistoric sites in the western Punjab appears low when compared to that of a well-surveyed arid region like Cholistan, then it could be due, at least in part, to factors other than pronounced differences in settlement intensity. Agriculture is one of the greatest destroyers of archaeological sites the world over and the extensive irrigation system built during the British period turned the semi-arid bar uplands into highly productive farmland. Across the Punjab the destruction of mounds for fields and/or fertilizer is quite common (*personal observation*). It was also noted in the Shahpur Gazetteer that saltpetre was "manufactured in considerable quantities from the numerous mounds in the cis-Jhelum tract which mark the sites of former villages" (Wilson 1897: 18). The shifting rivers of the Punjab have no doubt obliterated the remains of ancient settlements just as they have done to populated towns and villages in fairly recent times (Punjab Government 1898: 6-7). Other sites, especially low mounds and surface scatters of the kind that are easily observable in arid Cholistan, have likely been obscured by the deposition of 4000-plus years worth of alluvial sediments. Still others probably lay beneath the modern villages, towns and cities of this heavily populated region. Although all of this does not prove that the plains surrounding Harappa were as densely settled during the late prehistoric period settled as Cholistan evidently was, it does provide good reason to suspect they were probably not as sparsely populated as they might now appear to have been.

Our knowledge of the ancient settlement patterns of the Punjab is fragmentary and, because of the nature of the region, is likely to remain so. Nonetheless, the results of recent surveys have begun to provide a somewhat clearer picture of the region's cultural landscape during the late prehistoric period. Urbanization is a regional-scale phenomenon and cities cannot develop in isolation. The identification of contemporaneous settlements on the doabs surrounding Harappa demonstrates that it was far from being isolated.

The transforming cultural landscapes of the Indus Tradition

The cultural landscape of the Greater Indus region underwent several dramatic transformations during the fourth through second millennia BC (the period covered by Harappa's prehistoric/protohistoric chronological sequence). In this section, I review the various phases of the Regionalization, Integration and Localization eras of the Indus Tradition (Figure 2.6) along with pertinent concurrent phases in other traditions. The purpose of this review is two-fold. The first is to supply basic information (approximate age, geographic extent and important cultural associations) for cultural phases that are referred to repeatedly throughout this dissertation. The other is to provide cultural contexts/associations for the various rock and mineral artifacts that are the subjects of this study as well as for their potential geologic sources. Provenience studies reveal that, during certain phases, some varieties of stone used by residents of Harappa came from sources within the geographic area encompassed by settlements of the cultural phase to which they belonged. In such instances, the acquisition networks for those particular materials are considered *internal*. For other phases, certain stone resources were derived from locations outside of the area where sites of that phase are currently known to lie. Those acquisition

Figure 2.6: Indus Tradition cultures of the Regionalization, Integration and Localization Eras



networks are considered *external* and some form of interaction with the cultural group dwelling in the source region (if one has been identified) is implied.

Regionalization era (Early Harappan Period)

Period 1 (ca. 3300 to 2800 BC) and Period 2 (2800 to 2600 BC) at Harappa are defined by Indus Tradition Regionalization Era phases. Below, I discuss these along with the other Indus Tradition phases that existed during those periods. First, however, I must further discuss a term that is now widely used describe these phases and the time period.

The central thesis of Prof. Rafique Mughal's 1970 dissertation was that the early third millennium BC cultural phases of the Greater Indus region, which were at that time represented by excavated assemblages at Amri, Kot Diji, Harappa and Kalibangan and by surface collections from several other sites, shared with one another important attributes that, in a few centuries, would become distinctive features of the Indus (Harappan) Civilization. Synthesizing all of the data then available, Mughal argued that these phases, although regionally distinct, were direct historical antecedents to that civilization and collectively characterized them as being essentially *Early Harappan* in nature. Walter Fairservis (1975: 221) came to a similar conclusion around this time and proposed the same term. Based on newer excavation, survey and radiocarbon data, Mughal later (1990a) revised the definition to encompass phases in certain regions where they were previously not known and developments extending as far back as the mid-fourth millennium BC. "Early Harappan" is now widely (though not universally) used to denote those broadly related Indus Tradition Regionalization Era phases that existed during the millennium or so prior to the emergence of the Indus Civilization. It is used in that sense here.

ca. 3300 to 2800 BC

The founders and early residents of Harappa belonged to the *Ravi* culture (Kenoyer and Meadow 2000), which was one of the several regionally distinct Indus Tradition societies now recognized to have existed in the Greater Indus region during fourth to early third millennium BC (Figure 2.6 A; see also Figure 2.5 for site and region names). Archaeological remains representing this phase are, at present, only known at sites along the mid to lower reaches of the Ravi River drainage. Besides Harappa, two small Ravi settlements – Rajanpur and nearby Tibba Hissoka, lie approximately 80 km to the northeast of the site in the Ravi-Chenab (Rechna) doab (Dogar *in press*), near what appears to be one of the Ravi River's former watercourses. In addition, Kenoyer and Meadow feel (2000: 58-59) that the earliest levels (Period I) at Jalilpur (Mughal 1974), which lies approximately 70 km to the west-southwest of Harappa, probably represent a Ravi culture occupation at that site. The southernmost outcrop of the Kirana Hills at Shah Kot (noted with an arrow on Figure 2.5), which lies around 40 km north of Tibba Hissoka (the northernmost Ravi site), is the closest source of stone to any of the currently known Ravi Phase settlements.

Jalilpur Period I had earlier been designated a *Hakra* culture occupation (Mughal 1990b) and was seen to have close affinities to the nearly 100 sites of that phase identified in Cholistan – a region around 200 km to its south-southwest (Mughal 1997). The differing interpretations of early Jalilpur levels are not surprising or necessarily irreconcilable. Ravi Phase Harappans exhibited many similarities with their Hakra contemporaries living along the then active Ghaggar-Hakra river system, especially with regard to their lithic (to be

discussed) and ceramic assemblages (Kenoyer and Meadow 2000). This, in all likelihood, indicates that there was a great deal of interaction between peoples of the two regions. In addition to permanent agricultural villages (some up to 26 ha in area), numerous short-term camps with microlithic tool technologies have been discovered in Cholistan, which suggest that pastoral activities were a significant component of Hakra culture lifeways (ibid.). Such activities were likely one of the principle avenues through which long-distance interaction with peoples in distant regions took place. Some of this interaction was directed southward, as evidenced by the cluster of Hakra sites identified 300 km southwest of Cholistan near the Rohri Hills of northern Sindh (Mallah 2000; Shaikh et al. 2002). Ceramics described as "Hakra wares" have also been reported to the east of Cholistan in the earliest levels at Bhirrana (Rao 2006) and Rakhigarhi, in Haryana (Nath 2001). As studies of those wares continue, it is possible that they may be found to actually represent a regionally distinct phase with important parallels to the Hakra culture, much like the Ravi Phase at Harappa.

On the western margin of the upper Indus Basin, settlements belonging to the *Sheri Khan Tarakai* (abbreviated SKT on figures 3.4 and 3.6 A) phase and the subsequent *Tochi-Gomal* phase are found in an area extending from the Gomal Plain into the Bannu Basin (Khan et al. 2000, 2002b). Farid Khan and the other members Bannu Archaeological Project believe that the strongest cultural affinities, at least for the earlier phase, lie west of the region with sites in Afghanistan and southern Central Asia (Khan et al. 1991b: 170). However, important material culture analogies between the fourth and early third millennium BC peoples of the Bannu-Gomal region and those represented by Ravi Phase levels at Harappa in the Punjab have been noted by excavators working in both areas

(Kenoyer and Meadow 2000: 63; Khan et al 2002a: 87). This is a significant association in terms of this study because unlike Hakra Phase sites, most of which are clustered in a region almost entirely devoid of rock and mineral resources, the Sheri Khan Tarakai and Tochi-Gomal phase cultures were situated directly adjacent to the resource-rich highlands of the western Salt Range, Waziristan and northern Balochistan as well as along the natural routes through those regions into Afghanistan and, ultimately, Iran and Central Asia.

Far to the south, two other regionally distinct Indus Tradition cultures also emerged at this time. Several dozen sites of the *Amri* Phase are found across an area that extends from the highlands of Sindh Kohistan and the Kirthar Piedmont to a short distance out onto the plains of the lower Indus Basin (Casal 1964; Flam 1981). Slightly farther to the southwest in the Las Bela region of southern Balochistan, Period A levels (end of fourth millennium to around 2700 BC – Franke-Vogt 1997) at the site of Balakot constitute all that is presently known of the *Balakot* Phase (Shaffer 1992). George Dales' studies of the "Balakotian" ceramic assemblage (1974: 11) indicated that varying degrees of interaction existed with both Nal culture (a Balochistan Tradition phase) groups to the north and Amrian peoples to the northeast. Although ceramic parallels that would indicate a similar degree of interaction with the Regionalization Era cultures of the upper Indus Basin are not evident at Balakot, marine shell artifacts (usually bangle fragments) are found at Hakra, Ravi and Sheri Khan Tarakai phase sites (Kenoyer and Meadow 2000: 64; Khan et al. 1991a: 59; Mughal 1997: 68). Although this does not specifically link those cultures with the Amri and Balakot phases, it does demonstrate that long-distance trade networks extending from the upper Indus Basin to the Arabian Sea coast were in place by this time.

2800 to 2600 BC

The cultural landscape of the Greater Indus region at around 2800 BC remained a mosaic of distinctive regional societies. Those belonging to the Indus Tradition at this time were the *Kot Diji*, *Amri* and *Sothi-Siswal* phases (Figure 2.6 B). In parts of the Greater Indus region where survey coverage and site preservation are good (Cholistan and southwestern Sindh), it has become evident that three or four-tiered settlement hierarchies already existed during this period (Mughal 1990a: 192). Excavations at Harappa (Meadow and Kenoyer 2001), Kalibangan (Bala 2003; Joshi 2003), Dholavira (Bisht 1991), Rehman Dheri (Durrani 1988; Durrani et al. 1995b), Kunal (Khatri and Acharya 1995) and other sites with Early Harappan occupations have brought to light features such as massive platforms and fortification walls, the first cubical stone weights and stamp seals and post-firing graffiti on pottery and other types of evidence relating to the development of the Indus writing system (note that not every Early Harappan site, including most listed above, possesses all of these attributes). Many scholars are increasingly of the opinion an "early," "proto" or "incipient" form of urbanism had emerged in parts of the Greater Indus region by this period (Allchin and Allchin 1997: 205; Durrani et al. 1995b; Flam 1981: 183; Meadow and Kenoyer *in press* and 2001: 23; Mughal 1990a). Although not everyone is convinced that such designations are justified (for views to the contrary see Chakrabarti 1998: 46-47 and Possehl 1986: 95-96; 1990), it is at least clear that many of the technologies and innovations that are among Kenoyer's (1991a) necessary preconditions for the development of urbanized society (Figure 1.2) were, in some areas, already in place.

The most extensive cultural phase of this period was that of the Kot Diji culture, so named after the small site in northern Sindh near the Rohri Hills where it was first defined (Khan 1965). Period 2 levels at Harappa are entirely "Kot Dijian" in character. The scale of cultural integration represented by sites of this phase is enormous (Mughal 1992a). A distance of almost exactly 1,000 km exists between the northernmost known Kot Dijian settlement (*Hathial* – Khan 1983) and the southernmost one (*Phang* – Harvey and Flam 1993). Within that area, sites of this phase are found throughout Sindh (Flam 1981; Mallah 2000), Cholistan (Mughal 1997), northern Balochistan (Fairservis 1975; Mughal 1974a), the Gomal Plain (Durrani 1984), Bannu Basin (Allchin et al. 1986), the western Punjab Plain (Mughal et al. 1996); the Salt Range (Dar 2002) and to the northern edge of the Potwar Plateau (Halim 1972). Importantly for this study, numerous rock and mineral sources were now situated within the geographic area encompassed by settlements of the cultural phase to which residents of Harappa belonged. In addition, there is strong evidence that Kot Dijians were interacting with peoples of other traditions and phases living in potential source regions external to that area, such as the "Northern Neolithic" cultures inhabiting the mountain valleys of the northern Subcontinent at this time (Possehl 1999: 542-553; Stacul 1992, 1994). Ceramics of "indubitable" Kot Dijian character were discovered in the Neolithic levels of Burzahom in the Kashmir Valley along with agate and steatite beads that are almost certainly trade items from the Indus region (there are no local analogues for such beads but they are common at Harappa and other Indus sites) (Pande 2000: 392; Saar 1992). Such ceramics have also been recovered in third millennium BC levels at Ghalegay and several other sites in the mountain valley of Swat, NWFP (Stacul

1987). At the opposite end of the Greater Indus region, Kot Dijian sites are found in close proximity (in some cases less than 10 km) to those of the Amri Phase (Flam 1981). Kot Dijian ceramics at many Amrian sites provide evidence for both the contemporaneity of the two cultural phases and a high degree of interaction between them (Possehl 2002a: 117).

The Early Harappans that lived on the plains of the eastern Punjab and Haryana at this time have been defined as belonging to the *Sothi-Siswal* phase (Possehl 1999: 685). If one compares Sothi-Siswal and Kot Dijian ceramic assemblages across the regions where they found, a gradual "continuum of variation" in forms and stylistic traits is evident between them rather than a sharp boundary (Possehl 2002a: 123). This likely indicates that "strong lines of communication" existed between the peoples of these two phases (ibid.: 124). Sothi-Siswal Phase Early Harappans living at sites adjacent to the Himalayan foothills like Manda (Joshi and Bala 1982), Ropar (Sharma 1982) and Chandigarh (Shaffer 1981: 87) would have had excellent access to the rock and mineral resources of that region. Those at Mitathal (Bhan 1969) and other settlements in southern Haryana were best positioned to acquire copper and other resources found in the northern Aravalli Range. Doing so would have brought them into contact with Rajasthan-Mawal Tradition peoples (Ganeshwar-Jodhpura Phase), like those now known to have been dwelling at Ganeshwar since about 3000 BC (Agrawala and Kumar 1982; Rizvi 2007).

The Amri phase continued in southwestern Sindh at this time. Ceramic parallels suggest that Amrians had close ties with peoples of the *Nal* Phase of southern Balochistan. Shaffer (1992) defines the Nal culture as a separate phase in the Balochistan Tradition while Possehl (following Fairservis 1975) treats the Amri and Nal phases as two aspects of

a single Early Harappan cultural phenomenon (*Amri-Nal*), which was "bound together by the seasonal movement of agropastoralists and other itinerants" between the southern Balochistan highlands and the plains of lower Sindh (Possehl 2002a: 115-118). Although I continue to follow Shaffer's framework here, I have graded the blue shaded areas on Figure 2.6 B to reflect the approximate sphere of interaction between peoples of the two phases (light blue for the western area were Nal sites are predominantly located and a darker blue for the eastern region where Amrian sites tend to be found). As I noted earlier, there was also a Kot Dijian presence in southwestern Sindh at this time. Rock and mineral resources from locations within the interaction sphere of the Amri and Nal peoples could have entered the extensive Kot Dijian interaction networks at this point and then been transported through them to consumers at Harappa.

Finally, there is evidence suggesting that Early Harappan peoples may have begun to settle in northern Gujarat at this time and/or were interacting with indigenous non-Early Harappan peoples of that region to a significant degree (Possehl 1999: 603-612). In Kutch, ceramics with both Amrian and Kot Dijian cultural affinities are present in the earliest occupational levels (Stage I and Stage II) at Dholavira; a site which was a settlement that would subsequently become one of the five major Indus cities (Bisht unpublished 1993 report cited in Ajithprasad 2002). Early Harappan ceramics (both Amrian and Kot Dijian-like) have been reported amongst the local wares in the levels immediately below the Indus Civilization occupation at Nagwada on the North Gujarat Plain (Hegde et al. 1988, 1990). Prominent among the many rock and mineral resources of this region that Early Harappans may have wished to acquire are ornament-quality microcrystalline silicates and amazonite.

Integration era – 2600 to 1900 BC

By the mid-third millennium BC the regional cultures of the Early Harappan Period had largely coalesced into the urbanized society known as the Indus Civilization. In Shaffer's framework (1992) this is the *Harappan Phase* of the Indus Tradition. It represents an approximately seven century-long era during which peoples living in distant and ecologically diverse regions of northwestern South Asia (Figure 2.6 C, see also figures 3.1 & 3.5) were culturally, economically, and, perhaps to varying degrees, politically *integrated*. A system of well-developed, intensive and sustained inter-regional interaction networks made this possible. Archaeologically, the result was a large number of sites with remarkably similar material culture remains spread across an immense geographic area. Marking the approximate western extent of the main or "core area" (Mughal 1990a) of Harappan Phase settlements are Dabar Kot in northern Balochistan (Stein 1929), Nausharo at the foot of the Bolan Pass (Jarrige 2000) and Sutkagen-Dor on the Markan coast near the modern boarder with Iran (Dales 1962). Lothal in Gujarat (Rao 1979a, 1985) is one of the southernmost sites of this phase and the earliest levels at Alamgirpur in Uttar Pradesh (IAR 1958-59) indicate that Indus Civilization peoples were living as far eastward as the Gangetic Basin. Harappan Phase occupations are found along the northern margin of the upper Indus Basin at Chandigarh (Shaffer 1981: 87), Ropar (Sharma 1982), Manda (Joshi and Bala 1982), Musa Khel (Dani 1971) and at several sites in the Gomal Valley such as Maru (Khan et al. 2000). Importantly for this study, geologic sources for nearly all of the rock and mineral varieties used by residents of Harappa during this time (Period 3 at the site) occurred within (internal to) or very close to the Indus Civilization's core area.

Without the benefit of written records it is difficult to determine the degree to which the Indus Civilization was politically integrated. By 2600 BC, large urban centers had emerged at Ganweriwala in Cholistan (Mughal 1997), Rakhigarhi in Haryana (Nath 1998), Dholavira in northern Gujarat (Bisht 1991), Mohenjo-daro in Sindh (Marshall 1931b) and, of course, Harappa in the Punjab. Kenoyer (1997a) feels that these cities were regional loci of political and economic power and probably represent independent polities not unlike "city-states." Ratnagar (1991: 169), on the other hand, argues that many factors, including the widespread use of standardized "infrastructural elements" (bricks, chert and metal tools, carts, etc.), points to "political unification under one state." Over the course of the Indus Civilization's 700 year existence it is quite likely that the scale of political integration fluctuated (Kenoyer 1994b). Perhaps both scenarios were true at different times. Presently, however, it is not possible to state if such fluctuations actually occurred, much less when. In this study, I am only able to say whether or not a specific rock or mineral acquisition network appears to have been external or internal to the Harappan *cultural* "core area."

A pronounced degree of cultural integration during the Harappan Phase of the Indus Tradition is evident from the widespread use of very specific material items and symbols that reflect a common and deeply-held ideology (Miller 1985). However, older notions that sites of this phase exhibit a "uniformity" (Piggott 1950: 140), "monotonous regularity" (ibid.: 136) and "astonishing sameness" (Wheeler 1950: 29) over the enormous area where they occur have given way to research showing that important regional variations did exist, most notably in terms of ceramics styles and subsistence regimes (Possehl 1992b). Based on these variations as well as settlement patterns and geography, Possehl (1992b, 2002a)

has defined different Harappan “domains” within the Indus Civilization – e.g. Sindhi Harappan, Bahawalpur Harappan, East Punjab Harappan, etc. Even though this is a tempting way to conceptualize and organize cultural variability over this huge area, I am going to resist using Possehl’s “domains” here because I feel that doing so would suggest the existence of political, social and perhaps even ethnic divisions that have not yet been satisfactorily demonstrated. Although it is plain that, culturally, the Indus Civilization was an internally differentiated society rather than a monolithic one, for the purposes of this study the groups of people making it up are collectively considered “Harappan.”

Precisely where Harappan culture ended and non-Harappan began is not always clear cut, however. “Harappan” status has been given to some regional groups for which that designation, although not baseless, is arguable. For instance, during the latter half of the third millennium BC southern Balochistan appears to have been occupied by both Indus peoples and the locally distinct *Kulli* culture (Franke-Vogt et al. 2000). Kulli peoples did use some ceramics and iconographic elements that were Harappan in character. Possehl considers them to have been a highland variant of the Indus Civilization (Possehl 1986: 61) – i.e. “Kulli Harappan” (Possehl 1992b). Similarly, a large portion of the Saurashtra Peninsula of Gujarat was occupied by peoples that Possehl calls “Sorath Harappans” (Possehl 1992a). They too possessed many elements of Harappan material culture but they also lacked some important ones such as stamp seals. It is quite plain that there were strong connections between the Indus Valley and areas like the southern Balochistan highlands and Saurashtra at this time. Whether or not the peoples in the latter two regions represented highly distinctive variants of the Indus Civilization or were local groups who had absorbed

certain cultural elements from their Harappan neighbors remains to be determined, however. Therefore, on the Figure 2.6 C, the green-shaded area marking the extent of the Indus Civilization is faded out in the Kulli and Sorath culture areas so as to reflect where the "veneer" (a word I borrow from Dr. Richard Meadow) of Harappan culture is thinner.

Immediately north of the Indus Civilization, in the Bannu Basin, Gomal Plain and Potwar Plateau areas, there is evidence that the Kot Dijian phase continued concurrently with the Harappan Phase. Contemporaneity between the two phases is indicated by both radiocarbon dates and finds of items with clear Harappan affinities at otherwise wholly Kot Dijian-type sites in those areas (Allchin 1984; Dani 1971; Thomas and Allchin 1986; Xu 1990). Interaction with "Late" Kot Dijian Phase peoples would have afforded Harappans indirect access to the rich rock and mineral resources of the northern Pakistan highlands.

There is abundant evidence demonstrating that Harappan interaction networks extended well outside of the Greater Indus region during the Integration Era (Tosi 1993). The site of Shortughaï in northern Afghanistan (discussed on pp. 20, 51-52) provides some of the clearest such evidence. The fact that Harappans journeyed to (and presumably from) that distant settlement opens the possibility that rock and mineral resources occurring along the many routes through northern Pakistan and Afghanistan were accessible at this time. Toward the west, Harappan seals and beads have been found at a number of sites across the Iranian Plateau (Dales 1976; Heskel 1984; Lawler 2007; Tosi 1979). Seals and other items at Altyn Depe in Turkmenistan indicate that some interaction between Harappans and local Bactria-Margiana Tradition peoples took place within southern Central Asia (Hiebert 1995; Masson 1981). Beginning around the end of the third millennium BC, Bactria-Margiana

Tradition (BMAC phase) peoples were themselves making inroads into northwestern South Asia (Hiebert and Lamberg-Karlovsky 1992; Jarrige 1991a; Meadow 2002; Parpola 2005).

At the southern end of the Harappan world, there is ample evidence on both sides of the Arabian Sea for the existence of seaborne trade between the Indus Civilization and the ancient cultures of northeast Arabia (Chakrabarti 1998; Cleuziou 1992; Cleuziou and Tosi 1994; Edens 1993; Possehl 1997a; Rao 1979b; Ray 2003). Farther to the west, textual records suggest that Harappan merchants and craftsmen were living in Mesopotamia at this time (Parpola et al. 1977; Vidale 2004) and that numerous goods were being imported into that region from "Meluhha" – the Sumerian name for the Indus region (Asthana 1976; Chakrabarti 1990; Kenoyer *in press* c; Possehl 1996; Ratnagar 2004). What was traded to "Meluhha" in return is unclear as items of obvious foreign origin (Mesopotamian or otherwise) are extremely rare at Indus Civilization sites (Possehl 2002c). It might have been perishable goods that are now archaeologically "invisible" (Crawford 1973) or raw materials that were subsequently transformed by Harappan consumers. Ratnagar (2004: 199) has argued that silver was a Mesopotamian import while Kenoyer and Miller (1999) feel that the copper resources of Oman were the impetus for trade with that region.

Localization era – 1900 BC to <1300 BC

Around 1900 BC, the Indus Civilization began to undergo a significant transformation as many of its cities, along with the interaction networks that supported urbanized society in northwestern South Asia, were either abandoned or dramatically reduced in scale. Within a century or so three localized phases (Figure 2.6 D) had emerged in the previously integrated region – *Rangpur* in Gujarat, *Jhukar* in Sindh and *Cemetery H*

in the upper Indus Basin and western Gangetic Basin (Mughal 1992b). Although the peoples of these phases retained many cultural features that justify the use of the term "Late Harappan" to describe them, they had abandoned others (the Indus script, weights, stamp seals) that were hallmarks of the Indus Civilization. The particulars of the general "deurbanization" seen during the Late Harappan period and the reasons behind it are not yet fully understood but research in recent decades has made it clear that the outcome of the transformation was not the same in all parts of the Greater Indus region (Possehl 1997b; Sonawane 2002). In Sindh and Cholistan there was a precipitous decrease in settlement density while in Gujarat, the eastern Punjab, Haryana and western Gangetic Basin there were many more sites than in the previous phase. Evidence from Cemetery H (Period 5) levels at Harappa indicate that activity and innovation continued in the western Punjab at this time despite the apparent cessation of long-distance interaction networks with Sindh and Gujarat (Kenoyer 2005b). Finds of Cemetery H ceramics in the Swat Valley (Stacul 1985) show that interaction between the Indus plains and the mountainous north continued.

Chapter conclusion

Harappa's geographic position in center of the Punjab Plain was optimal from the standpoint of its being centrally located. Geologically, however, this was a resource-poor area. The site's residents had to import all stone from sources located no less than 120 km away. Access to those sources shifted as the cultural landscape that they were a part of transformed over time. It was within these contexts that the artifacts making up Harappa's rock and mineral assemblage were acquired, used and discarded. In the next chapter, I review the research strategies and methods used to identify the sources of those artifacts.

Chapter 3

Strategies and methods for sourcing stone and metal artifacts

Chapter 3 - Strategies and methods for sourcing stone and metal artifacts

Chapter introduction – Strategies and methods

In order to address the lines of inquiry outlined in Chapter 1, it is necessary to know precisely what kinds of rocks and minerals are present in Harappa's artifact assemblage and, for select varieties of those materials, to ascertain which geologic sources they were most likely acquired from. The purpose of this chapter is to review the various research strategies and methods that were employed to accomplish those two tasks.

Reeves and Brooks (1978) outlined a series of steps (Figure 3.1) for successfully determining the geologic provenience of rock and mineral artifacts, which will serve as a guide for the presentation of this chapter. I begin with a discussion of the importance of utilizing the extensive body of geologic literature relating to South Asia as the primary reference source for locating the natural occurrences of the different rock or mineral types being investigated (Step A). Emphasis is also placed on the benefits of directly working with geologists. The discussion then shifts to the geologic field studies that were necessary

Figure 3.1: Steps for successfully determining the geologic provenience of rock and mineral artifacts (adapted from Reeves and Brooks 1978: 364-365)
A. Locating the natural occurrences of the rock or mineral type being investigated.
B. Collection of a representative range of samples from each potential source area.
C. Demonstrating that the chemical / isotopic / mineralogical variability *between* different geologic sources is greater than the variability *within* individual sources.
D. Establishing a set of analytical parameters that will allow geologic sources to be distinguished from one another with a high degree of confidence.
E. Analysis of rock and mineral artifacts and assignment to a probable geologic in accordance with the criteria established in D.

for both collecting a representative range of geologic samples from each potential source area (Step B) and for confirming or refuting the existence and/or nature of certain rock and mineral occurrences. I then move on to the issue that ultimately underlies the success or failure of any stone or metal artifact sourcing study – demonstrating that the chemical, isotopic or mineralogical variability *between* the different geologic sources under examination is <u>greater</u> than the variability *within* any individual source (Step C). Many factors contribute to successful source discrimination, such as the choice of sampling strategies (discussed in relation to Step B) and analytical methods (discussed in relation to steps D and E). One issue, which is often not given due attention, relates to the selection of the appropriate geographic scale on which to define stone or metal "sources." After examining the issue of scale and the expectations of provenience resolution stemming from it, I proceed on a series of overviews outlining the various methods used to identify and/or characterize archaeological and geologic samples for this study. Also discussed are the analytical methods that were chosen to evaluate the quantitative data obtained from the characterization of selected varieties of stone or metal. Through the application of these methods, parameters were established that allow different geologic sources to be distinguished from one another with a high degree of confidence and artifacts to be assigned to them based on their chemical/isotopic/mineralogical properties (steps D and E).

In the conclusion of this chapter, I stress that statements regarding the geologic provenience of stone or metal artifacts are always *provisional*, regardless of how comprehensive or statistically significant the datasets they are based on may appear to be.

Research strategies

In this section the research strategies that were used to locate potential rock and mineral sources, assemble a collection of geologic samples for analysis and to define suitable scales of provenience resolution are discussed.

Using primary geologic references materials to locate potential sources

There have been several major broad-scale studies (Fentress 1976; Lahiri 1992; Ratnagar 2004) of Harappan trade networks that examined multiple varieties of stone and metal to construct models of proto-historic resource access and exchange. However, to locate the rock and mineral sources that were potentially used in the past, those researchers relied heavily upon colonial-era British Government district gazetteers and secondary references such as the source identifications suggested or cited by the writers of early excavation reports. Consequently, their interpretations have serious limitations due to the imprecise, incomplete and occasionally spurious nature of their principal reference materials. I am not suggesting that those types of sources have no value and should be ignored. On the contrary, the reports of late 19th and early 20th century civil servants and archaeologists are sometimes the sole source of information on certain mineral deposits. I myself frequently cite these references throughout this dissertation. However, they alone do not provide a comprehensive picture of South Asian rock and mineral resources and, because their writers usually did not visit geologic occurrences themselves, misidentification of source locations and of the materials themselves could easily have been made. For these reasons, literature of this kind should not be considered the “best

sources" (Possehl 1999: 173) to turn to for primary reference material when delineating potential resource areas for rock and mineral artifact provenience studies.

A substantial body of scholarly literature relating to the geology of South Asia exists and was accessed for this dissertation as the *primary reference material* for locating the potential sources of the rock and mineral artifacts found at Harappa. Among the most useful publications were those produced by national government agencies such as the Records, Memoirs and Bulletins put out by the Geological Survey of India and the Geological Survey of Pakistan. Publications by state agencies, such as the Department of Mines and Geology, Government of Rajasthan were also valuable sources data. Dozens of university geology departments in both India and Pakistan regularly publish journals, conference proceedings and books detailing the geologic resources of the state or region that they represent. For decades institutions such as Pakistan's Centers of Excellence (in Geology and Mineralogy), the Geological Society of India and the Wadia Institute of Himalayan Geology have conducted and published groundbreaking geologic research. Public reports produced by organizations like the Gujarat Mineral Development Corporation and the Federally Administered Tribal Areas Development Corporation (FATADC) were also excellent sources of data on mineral resources in those areas. New geologic overviews (e.g. Bender and Raza 1995; Kazmi and Jan 1997) have recently come out that are far more accurate and comprehensive than earlier ones. Lastly, the unique nature of the Subcontinent's geology has attracted researchers from around the world who have collaborated with their South Asian colleagues and published their results in a wide range of international journals.

Early on in my research I realized that it would be highly beneficial to work closely with Pakistani and Indian geologists in the effort to locate potential rock and mineral sources, as well as on other aspects of this project. The first and most obvious reason is that geologic materials (their properties, the processes that create them and their economic uses) are the focus of their discipline. Field geologists know their research areas intimately and, in the course of their surveys, often see and note old mines, working areas and sometimes even archaeological sites. Geochemists and economic geologists can provide valuable insights into the nature, variability and locations of mineral deposits and it is often the case that source samples for initial analysis can be acquired from their existing collections. Finally, the disciplines of archaeology and geology share many common features (stratigraphy, time depth, change) and most geologists that I had the privilege to work with have had a great personal interest in the human past.

Sampling and field-checking potential sources

After locating the potential geologic sources of the different rock and mineral artifacts found at Harappa, the next task was to obtain materials from them for use in comparative analyses. This could be accomplished only by implementing an extensive strategy of field survey and sampling. In a region as vast and diverse (geographically, geologically, culturally and politically) as northwestern South Asia this was a big undertaking, but one that was absolutely essential to the success of my research. Several hundred individual source locations were visited over the course of four years (2000-2004) and a representative range of material was collected from each one so that intra-source and extra-source geochemical variability could be satisfactorily assessed. Sampling strategies

varied depending on the type of rock or mineral being studied (details on individual varieties are provided in upcoming chapters) and on the geographic extent over which a "source" occurred (an issue discussed in the next section). In most instances, a minimum of 20 to 25 samples per source were obtained, which is generally considered to be an amount sufficient for making statistically meaningful assessments and comparisons (Malyk-Selivanova et al. 1998: 667; Truncer et al. 1998: 25). Although no formal collection procedures were employed (such as the laying out of a transect or grid across a deposit and taking samples at predetermined or random intervals), with the help of my colleagues in the geosciences a concerted effort was made to acquire samples that were representative of a deposit, both spatially and in terms of the full range of macroscopic varieties present in each locality. Whenever possible (and again depending on the type of material), samples were removed from fresh exposures using a geologic hammer rather than taken from loose contexts such as surface scatter or mine tailings.

Field surveys were also essential for reasons that went beyond just compiling a collection of geologic comparative materials. Misidentification/misrepresentation of a rock or mineral deposit sometimes happens, even in the geologic literature. By personally visiting a reported occurrence I was able to confirm or refute its existence and/or to clarify the nature of the material found there. My survey of steatite sources (Chapter 7) illustrates the benefits of employing of this strategy. Deposits of steatite were reported in the northern part of the Zhob District, Balochistan at two locations (Ahmad 1975: 135). When I visited the region I found that it was actually chlorite and serpentine, rather than steatite, which occurred at those locations. Field-checking also helped to clarify the nature of

steatite deposits worked along the margins of the Peshawar Valley at Jamrud (Abbas et al. 1967) and Kund (Qaiser et al. 1980). Visits to those deposits revealed that the material occurring there was of an extremely low-grade and not at all of the quality Harappans used for manufacturing purposes. Lastly, in the course of a field survey previously unpublished sources may be identified, as was the case when I located several unreported steatite mines in the Las Bela District of southern Balochistan. Although these deposits were well known locally and had apparently been worked for quite some time, to my knowledge no reference to them had ever appeared in print.

The "Provenience Postulate" and defining a geographic scale of provenience resolution

Underlying the present study is the assumption known as the "provenience postulate" (Weigand et al. 1977: 24). This assumption holds that determining the source of a stone or metal artifact "is possible as long as there exists some qualitative or quantitative chemical or mineralogical difference between natural sources that exceeds the qualitative or quantitative variation within each source" (Neff 2000: 107-108). A successful outcome to provenience research is, therefore, largely dependent upon the natural properties of the rock and mineral sources being examined, adequate sampling of those sources (discussed above) and the application of suitable methods for both characterizing materials collected from them and analyzing the resulting data (discussed below). However, an additional factor that has great bearing on the success of a study is the consideration given to the geographic scale on which "sources" are defined and the expectations of provenience resolution that stem from the definition of this scale.

For example, certain types of stone occur as well-circumscribed bodies (outcrops/pockets/zones) of material that, individually, have highly distinctive chemical compositions. Obsidian – a volcanic glass for which the geologic proveniences of artifacts made from it can frequently be resolved down to the level an individual outcrop (Williams-Thorpe 1995), is probably the best example of this type. At the other extreme are materials that occur (either contiguously or intermittently) across broad geographic areas and are fairly homogeneous throughout. Cackler and others (1999) had difficulty differentiating individual chert outcrops in northern Belize because they were all, in essence, part of a single extensive geologic formation. Such a situation, when it occurs, need not always mean that the geologic provenience of an artifact is irresolvable. A "source" can be defined as either a single location or a collection of many locations in "geographic space" (Neff 1998: 116). Depending on the extent of the study area and the diversity of the geology within it, the scale at which a "source" is defined may be expanded to include materials sampled from multiple geologically related locations.

The current examination of Harappan acquisition networks involves numerous rock and mineral types and multiple scales of provenience resolution. The locations where gem-quality vesuvianite-grossular garnet (Chapter 9) and high-quality agate (Chapter 8) can be found are limited in number and in geographic size. Deposits of steatite (Chapter 7) and limestone (Chapter 11), on the other hand, are much more numerous and occur over extremely broad areas. Extensive sampling, characterization and analysis of the latter two materials have indicated that, in some instances, "sources" are best defined at a regional scale. For a material like steatite it may, in the end, only be possible to make a statement

such as "the stone that these artifacts are composed of appears to have been derived from deposits located in the NWFP of northern Pakistan." For steatite artifacts from a site situated within that region, like Sarai Khola, this would provide little information other than the material was probably acquired locally. However, in terms of Harappa – a site for which potential steatite sources lay roughly 300 to 900 km away in all directions, this level of resolution is more than sufficient to provide valuable insights into the extent and directions of long-distance resource acquisition networks.

Methods of material identification and characterization

In this section, I review the various methods that were used to identify and/or characterize the archaeological and geologic materials examined for this dissertation.

Visual inspection/comparison and basic mineralogical testing

The 56,000+ stone and metal artifacts recovered during HARP excavations were initially classified by rock or mineral type based on visual inspection by HARP co-director Dr. Mark Kenoyer, who has had over 30 years experience studying lithic materials from archaeological sites in South Asia. For this dissertation, I re-examined the majority of these artifacts primarily to familiarize myself with the range of materials found at the site but also to locate artifacts for which initial identifications needed to be revised or clarified. Illustrated rock and mineral handbooks and field guides (Pellant 2002; Pough 1988) were especially valuable tools in this effort. Direct comparisons were made between artifacts and geologic samples that I had collected from sources around the Greater Indus region. In May of 2000, with the permission of the Director-General of Archaeology and Museums, Government of Pakistan, I assembled a "traveling" set of samples that contained 200 rock

and mineral artifacts from Harappa (all of them small non-diagnostic fragments) representing the full range of material varieties and sub-varieties present at the site. These archaeological samples were compared to geologic samples in the extensive collections housed at the Geological Survey of Pakistan's museum in Quetta, the Department of Geology, University of Peshawar and the Pakistan Museum of Natural History in Islamabad. Numerous professional geologists from these institutions generously provided their expert assessments of the identities and the probable origins the various rock and mineral artifacts in the set. Their identifications enabled me to plan a comprehensive field survey for the purpose of collecting my own geologic samples for comparative analyses.

Simple, non-destructive mineralogical tests were conducted on a number of archaeological samples. The most common test used was that to determine a stone artifact's *density*, which "is a fundamental and characteristic property of each mineral and, as such, is an important determinative property" (Rapp 2002: 21). The density of a mineral is expressed as its *specific gravity* (SG) – the ratio of its weight to the weight of an equal volume of water. A Hanneman direct reading specific gravity balance was used at Harappa to make SG measurements on several hundred artifacts. Another basic test used was that of a mineral's *hardness*, that is, its resistance or susceptibility to abrasion (scratching) relative to ten minerals on an ordinal scale first developed by Friedrich Mohs in 1812 (Appendix 3.1). Mineral types that resembled one another could often be differentiated using a simple scratch test. For example, a translucent green flake composed of vesuvianite-grossular garnet (hardness ≈ 7) will scratch feldspar (hardness 6) and so can be easily be distinguished from an identical looking serpentine flake (hardness ≈ 4), which will not.

X-ray diffraction (XRD) analysis

X-ray diffraction (XRD) analysis enables one to unambiguously determine the identity of crystalline substances (Henderson 2000: 10). Over 100 rock and mineral artifacts from Harappa were characterized using this technique, which involves bombarding a small amount of powdered rock sample with X-rays so as to cause the electrons within it to vibrate. The vibrating electrons reflect a portion of the X-ray radiation as waves that reinforce themselves in an effect called *diffraction* (Klein and Hurlbut 1977: 277). The patterns that the diffraction effects create are recorded and provide precise information about the atomic structure(s) of the mineral(s) within the sample. It is the only technique used here that can accurately distinguish between mineral *polymorphs* (minerals sharing the same chemical composition but having different crystal structures). For example, quantitative data on the abundance of silicon dioxide in a sample can be obtained using electron microprobe analysis (discussed below), but only with XRD is it possible to determine which polymorph (*quartz*, *tridymite* or *cristobolite*) it is (Henderson 2000: 11).

Approximately half of the XRD analyses conducted for this dissertation were made on the Scintag PADV X-ray diffractometer at the S. W. Bailey X-ray Diffraction Laboratory, Department of Geology and Geophysics, University of Wisconsin–Madison. Diffraction data were output in digital form and interpreted using the program JADE 6.0. The other half of the analyses were made at the Center of Excellence in Geology, University of Peshawar on an older instrument that did not possess a computer interface. The XRD patterns were recorded on paper “strip-charts” and the peak positions and relative intensities had to be physically measured and manually recorded. These data were then

interpreted using mineral phase search manuals published by the International Centre for Diffraction Data. Both the Madison and the Peshawar diffractometers were run at 40 kv and 30 ma and, for most samples, scans were run at a 2-theta angle from 5° to 65° with a .02° step size and a .25 second count time.

Electron microprobe analysis (EMPA)

Electron microprobe analysis (EMPA) is both a method with which to acquire compositional data on solid materials as well as a powerful micro-imaging tool (Reed 2005). Samples are affixed in epoxy within a tubular analysis cartridge and then a flat surface is ground, polished and given a thin carbon coating. Upon this surface the "probe" can focus a beam of electrons on an analytical area as small as 1 μm or micron (0.001 millimeter). This makes it a useful tool for examining rocks having multiple mineral phases and minute inclusions. Chemical characterizations can be done using either the energy dispersive spectrometry (EDS) or wavelength dispersive spectrometry (WDS) capabilities of the probe. EDS measures the X-ray energy emitted from the area under the beam of electrons and permits quick reconnaissance and qualitative chemical characterizations of materials (Lund 1994). WDS measures electrons diffracted by the crystal structure of the material under the beam (Lund 1995). When calibrated with known standards, highly accurate quantitative chemical data can be obtained using WDS. Micro-imaging of materials using backscattered electrons (BSE) works on the same principle as scanning electron microscopy. All EMPA of archaeological and geologic samples in this dissertation was conducted under the direction of Dr. John Fournelle on a Cameca SX50/51 electron microprobe at Department of Geology and Geosciences, University of Wisconsin-Madison.

Spectrometric analysis

Spectrometric (spectroscopic) analysis includes many different methods and types of instruments (Pollard and Heron 1996: Chapter 2). Highly accurate data on the elemental composition of a substance can be collected by observing the spectrum of light emitted when the atoms composing it are excited (atomic emissions spectrometry). Elemental as well as isotopic data may be obtained by directly detecting ionized atoms that have been separated according to their mass-to-charge ratios (mass spectrometry). Excitation or ionization of a sample for analysis can be achieved by various means but the use of an inductively-coupled plasma (ICP) torch is becoming increasingly common (Taylor 2000).

Spectrometric analyses were conducted on artifacts and geologic samples composed of alabaster, limestone and various metals (lead, silver and copper). Limestone and metals were analyzed using the two ICP spectrometers at the Laboratory for Archaeological Chemistry (hereafter LARCH), University of Wisconsin-Madison, under the direction of Dr. T. Douglas Price and Dr. James Burton. The first instrument was an Applied Research Labs Model 3520 inductively-coupled plasma - atomic emission spectrometer (ICP-AES), which can detect and quantify dozens of elements at sub-parts-per-million concentrations (see Burton and Simon 1993 for elemental detection limits and precision typical of this instrument). The second was a Finnegan MAT ELEMENT I high resolution, magnetic-sector inductively coupled plasma-mass spectrometer (ICP-MS), which can obtain elemental and isotopic data at concentrations in the parts-per-quadrillion range. Full details regarding sample preparation and analysis, which varied according to the material being analyzed, are provided in Chapter 11 for limestone and in Chapter 12 for metal artifacts.

The analysis of alabaster artifacts and geologic samples (Chapter 10) required the use of spectrometers not available at the LARCH. Sulfur isotope compositions of were determined by Chris Eastoe at the Isotope Geochemistry Laboratory, Department of Geosciences, University of Arizona using a continuous flow isotope ratio mass spectrometer (CFIRMS). High precision strontium isotope assays of alabaster samples were made by Joel Blum and Andrea Klaue at the Department of Geosciences, University of Michigan–Ann Arbor, using a thermal ionization mass spectrometer (TIMS). Full details on these instruments, sample preparation and analysis are provided in Chapter 10.

Instrumental neutron activation analysis (INAA)

Instrumental neutron activation analysis (INAA) – a highly accurate and precise method for quantifying the major, minor and trace element compositions of materials, has been used by archaeologists around the world in efforts to determine the proveniences of a wide range of artifact types (Glascock and Neff 2003). In South Asian archaeology, this technique has, up until now, been exclusively applied to provenience studies of ceramic artifacts such as figurines (Possehl 1994), stoneware bangles (Blackman and Vidale 1992) and pottery (Méry and Blackman 1999; R.P. Wright 1984). For this dissertation, INAA was used to characterize geologic samples and artifacts composed of chert, steatite, agate-carnelian, vesuvianite-grossular garnet and limestone.

All rock samples subjected to INAA were prepared for analysis at the LARCH. Fresh, unweathered material was preferred for analysis. For geologic samples, either a small chip (approximately one gram) was struck from a freshly broken surface toward the interior of the sample and then crushed into a coarse powder with a steel mortar and pestle

or, for softer stone (steatite and some limestones), a tungsten carbide drill was used to burr-off the exterior surface of a small area on a sample and then drill directly into the fresh material, creating powder in the process that could used for analysis. Drill bits were carefully cleaned after each was sample was taken. Should contamination from the bit itself have occurred, it would be recognizable as a tungsten "spike" in the INAA spectrum during analysis (Truncer et al. 1998: 29). Archaeological samples were first cleaned in an ultrasonic bath of purified water. Removal of material was dependent on the size nature of the artifact. Generally around 0.5 to 1 gram of material was chipped off of hard stone artifacts and lightly pounded in the steel mortar into smaller (< 1 mm) pieces. The pieces were examined under low magnification and those that were free of cortex, patina or other surface features were selected for analysis. Artifacts made of softer stone were sampled using the tungsten drill described above. For both geologic samples and artifacts, exactly 200 mg (± 1 mg) of sample was loaded into polyethylene vials. Using a diamond scorer, sample numbers were etched onto the vials, which were then sealed by friction welding.

Sample analysis was conducted at the University of Wisconsin's Nuclear Reactor (UWNR) research facility by the team supervised by lab director Robert Agasie. INAA provides precise data on the elemental composition of a material. Elements within samples are first made radioactive, or *activated*, by exposing them to a neutron flux, after which the gamma ray emissions produced as radioactive elements decay were detected and counted (see Glascock and Neff 2003 for full details on this technique). A series of vials containing a standard (Canadian Centre for Mineral and Energy Technology Reference Soil Sample SO-4) were irradiated with the samples to calibrate for variations in exposure to the neutron

flux (Robert Agasie and Kevin Austin, UWNR *personal communication*). Depending on an element's half-life, different irradiation and count times were necessary. For the "short" count at the UWNR, each vial was irradiated for 3 seconds and, after a 15 to 16 minute decay time, a 300 second count was performed. For the "long" count, sample vials were irradiated for 7,200 seconds and, after a decay time of approximately seven to ten days, a 3,600 second count was performed. The UWNR facility employs a high purity Ortec Geranium Detector coupled with a PCAII PC-based multi-channel analyzer to detect specific gamma ray emissions emitted by the irradiated samples to determine the amounts of individual elements present within them. The fractional proportions of the elements detected in each sample were reported in parts per million (ppm). After the results were screened of elements that failed to be detected in all samples or had high count-rate standard deviations, the data could be subjected to multivariate statistical analyses.

Methods of data analysis

The application of the characterization methods outlined above to the different sets of archaeological and geologic samples examined for this dissertation resulted in large amounts of raw, highly varied types of quantifiable data. Because these results were used to determine the probable geologic provenience of stone and metal artifacts (and, ultimately, to support statements about the behaviors of ancient Harappans), the methods by which they were evaluated had to be carefully chosen. Much has been written regarding the numerous approaches to the analysis of quantifiable archaeological (Baxter 1994, 2003; Shennan 1997) and geologic data (Davis 1986). In this section, I discuss the methods that are featured in this dissertation and the reasons for choosing to employ them.

Preliminary data analysis / bivariate plotting

Prior to any statistical manipulation, multiple combinations of isotopic or elemental (after being log normalized) values in a dataset were compared on simple bivariate plots using the program DataDesk 6.0. This exploratory procedure was conducted to determine if, at this initial level, groups of samples from different geologic sources could be clearly differentiated from one another. For sets composed of isotopic data, like those produced for alabaster (Chapter 10) and lead (Chapter 12), this was indeed possible through bivariate (and in some cases even univariate) plotting of measured values alone. For other datasets, such as that for limestone (Chapter 11), bivariate plots of selected elemental values produced reasonably good separation between sources but multivariate analysis was found to work somewhat better. In such instances, both methods will be presented for comparison. For most of the rock or mineral datasets, however, these preliminary analyses indicated that groups of samples belonging to different geologic sources could not be easily distinguished using simple bivariate plots alone. More robust, multivariate approaches were required.

Multivariate approaches

Choice of methods

For this dissertation, canonical discriminant analysis (CDA) was the most suitable method for using multivariate data to differentiate sets of samples from various geologic sources and to assign provenience to archaeological samples. CDA is different from other statistical approaches such as principle component analysis or cluster analysis – two methods widely employed in provenience studies of archaeological ceramics (Glascock et

al. 2004), in that it begins with the presumption that a dataset already has a well-defined structure (Baxter 1994: 185). There is no need to assess patterns of variance or clustering in an effort identify structures that may (or may not) represent meaningful groups, simply because groups with known members have already been defined in the dataset. Here, the known groups are the sets of geologic samples that I have personally collected from sources across Pakistan and India. Although the degree to which it is possible to differentiate the various geologic sources within a dataset is initially unknown, there is never any ambiguity whatsoever as to whether or not the samples representing those sources actually belong to them. When groups are known *a priori*, CDA is the most suitable multivariate technique to use (ibid.: 81). It has been used in provenience studies of several of the same materials examined in this dissertation including steatite (Truncer et al. 1998), chert (Craddock et al. 1983) and limestone (Holmes and Harbottle 2003).

Certain situations arose throughout this study for which the use of a supplementary multivariate statistical method proved to be worthwhile. For instance, a large set (n = 140) of archaeological steatite from Harappa was analyzed (Chapter 7) and it is useful to know if multiple geochemically distinct groups of materials may be represented among the samples making up that set. Cluster analysis was chosen as the appropriate method with which to evaluate this possibility. This method, which actually encompasses a many different techniques (Baxter 1994: 140), can be used in tandem with CDA as a way to validate and graphically complement observed clusters of unknown samples that, in the case of stone artifacts, may be from the same geologic formations (ibid.: 165, 204-206).

All multivariate analyses were made using the statistical program SPSS 11.0.

Canonical Discriminant Analysis

Canonical discriminant analysis (CDA) was used to make geologic provenience determinations for rock and mineral artifacts in five of the upcoming chapters. For details on the complex mathematics underlying this method one should seek out Michael Baxter's treatises on statistical applications in archaeology (Baxter 1994, 2003). Here, I provide general overviews of the two main features of CDA: discrimination and classification.

Discrimination

CDA makes two important presumptions of a dataset: 1) that it is composed of distinct groups whose individual members are known and 2) that it contains all possible groups (Baxter 1994: 185-186). During the analysis of a dataset, one or more linear combinations of variables called *discriminant functions* are generated, each of which are intended to produce the maximum degree of separation (discrimination) possible between the groups of individual cases being assayed. If a set is composed of two groups then just one discriminant function is possible as there is only a single dimension between them that can be evaluated. Analysis of datasets made up of larger numbers of groups results in the generation of multiple functions because additional dimensions can be considered. Displaying the results of analyses involving three or more groups in a two dimensional format is accomplished by creating a bivariate plot of the dataset using the *first* and *second* functions (which are the first and second most significant discriminators) as the axes. Individual members of a dataset are plotted by their *discriminant scores*, which are the values that result when discriminant functions (unstandardized canonical discriminant function coefficients) are applied to each case. In essence, CDA collapses the multiple

measurements made for a case down into a single variable (Davis 1986: 479). The *optimal* end result is a scatterplot on which each group is represented by a separate distinct cluster of datapoints (cases), all of which actually belong to the groups they are in.

Optimal separation between groups of samples in a dataset is not always achieved, however. The clusters of datapoints representing a group may overlap with one another – sometimes considerably. Visual examination of scatterplots is the really not the best way to accurately assess how well groups were differentiated using CDA. Discrimination success is better evaluated through "cross-validation" (Baxter 1994: 204). SPSS 10.1 has a cross-validation feature called "leave-one-out" classification. In this procedure, each member of the dataset is omitted from the group it belongs to and classified (a process discussed in the following section) in relation to the dataset as an *ungrouped* case. A percentage is generated based on the number of cases in the dataset that were correctly assigned to the groups that they actually came from. This percentage provides a general indication of how good group separation is and a way to compare discrimination success from different stages of analysis.

Classification (and misclassification)

The same discriminant functions that were generated to differentiate known groups can also applied to individual cases of unknown origin to classify them according to which group or groups they most closely resemble. These "unknowns" (stone artifacts as well as the geologic samples left out of their groups for cross-validation purposes) are treated *ungrouped* cases and each is placed (according to its discriminant scores) on a bivariate plot in relation to the defined groups of a dataset. The point in space where the mean of a

group's members' discriminant scores is situated is called a *group centroid*. An ungrouped case's similarity/dissimilarity with the two or more group centroids in a dataset is established in terms of *Mahalanobis distance* – a statistical measurement that takes into account correlations between variables (Baxter 2003: 70). An individual case shares one Mahalanobis distance value with each group and it is classified as belonging to (or predicted to most likely belong to) the group for which that value is the smallest.

Two quick caveats need to be made regarding CDA classifications/predictions. First, because the method presumes that a dataset contains all possible groups, every ungrouped case considered receives a *predicted group membership* (PGM). This does not mean that the cases definitively belong in the groups that they have been assigned to or, for that matter, to any of the other groups in a set. There is always the chance that the classification for an archaeological sample (ungrouped case) will change when materials from additional geologic sources (known groups) are eventually added to the dataset. Secondly, there is the possibility that an artifact may also be misclassified even when the source from which it derived is represented as a group in the dataset. Misclassification might occur because of poor separation (discrimination) due to geochemical similarities between the sources being considered and/or because an artifact is an outlier that is situated nearer to the centroid of a source different from its own. In cases when the *first* PGM is questionable, it is sometimes useful to examine the *second* PGM (determined by the second nearest group centroid). In certain cases it *could* be the actual source. Classifications made throughout this dissertation are evaluated on a case-by-case basis in light of overall cross-validation success percentages as well as, occasionally, second PGM determinations.

Cluster Analysis

"Cluster analysis is the generic term for a wide range of methods for discovering homogeneous groups or clusters in a set of data" (Baxter 2003: 90). The various approaches employed in this study fall into a category of methods known as *hierarchical clustering*, which essentially works by either building up (agglomerative) or breaking down (divisive) a dataset into groups based on different measurements of their members' similarities/dissimilarities. Discussions of the different algorithms and distance measurements that may be applied to a dataset to produce clusters can be found in any one of several excellent books written on statistical analysis in archaeology (Baxter 1994, 2003; Shennan 1997). Although some consider the *average linkage* technique to one of the better hierarchical methods (Shennan 1997: 254), there is no one method that is clearly to be preferred over others. Multiple methods can be applied in an exploratory manner to observe how they compare. If the "structure in the data is reasonably clear and captured by all of the competing methodologies" then one may be "reasonably confident that a revealed structure is 'real'" (Baxter 1994: 160).

The result of a cluster analysis (CA) is most commonly displayed as a *dendrogram* – a series of connected straight lines branching out like limbs on a tree. The terminal ends of the branches signify individual cases. Similarity between any two given cases is represented by their distance to each other along the branches of the tree rather than by their proximity to each other on its terminal end. Determining the number of separate clusters that are represented on a dendrogram (in a dataset) is very much a subjective endeavor and, once again, can be facilitated by comparing multiple clustering strategies.

Chapter conclusion – Statements of provenience

For this study, an effort was made to be as comprehensive as possible with regard to locating the geologic sources that Harappans potentially acquired rock and mineral resources from, to collect representative samples from as many of those sources as possible; to define the best scale of provenience resolution, to employ the most appropriate methods of material identification and characterization and to choose those analytical methods that were best-suited for examining the different types of data that were produced. Nonetheless, any statement made in this dissertation regarding the geologic provenience of a stone or metal artifact should always be considered as *provisional*. The study area is vast and the possibility exists that the true source of a particular material may not have been located and/or sampled. Artifact provenience determinations may need to be revised when additional sources are eventually considered. The strongest statement of provenience that can be made at present or, for that matter, at any time in the future (regardless of how many sources and samples are eventually incorporated into a dataset) is: "given all of the sources examined, artifact X appears most chemically (or isotopically or mineralogically) analogous to geologic samples analyzed from source Z or from source region Z." Still, although always provisional, such a statement and the data that it is based upon can be used to construct a compelling argument for a link between Harappa and a specific source area.

Prior to constructing such arguments, however, it is first necessary to present Hararappa's rock and mineral artifact assemblage in detail and examine its spatial and temporal distribution at the site.

Chapter 4

The rock and mineral artifact assemblage at Harappa

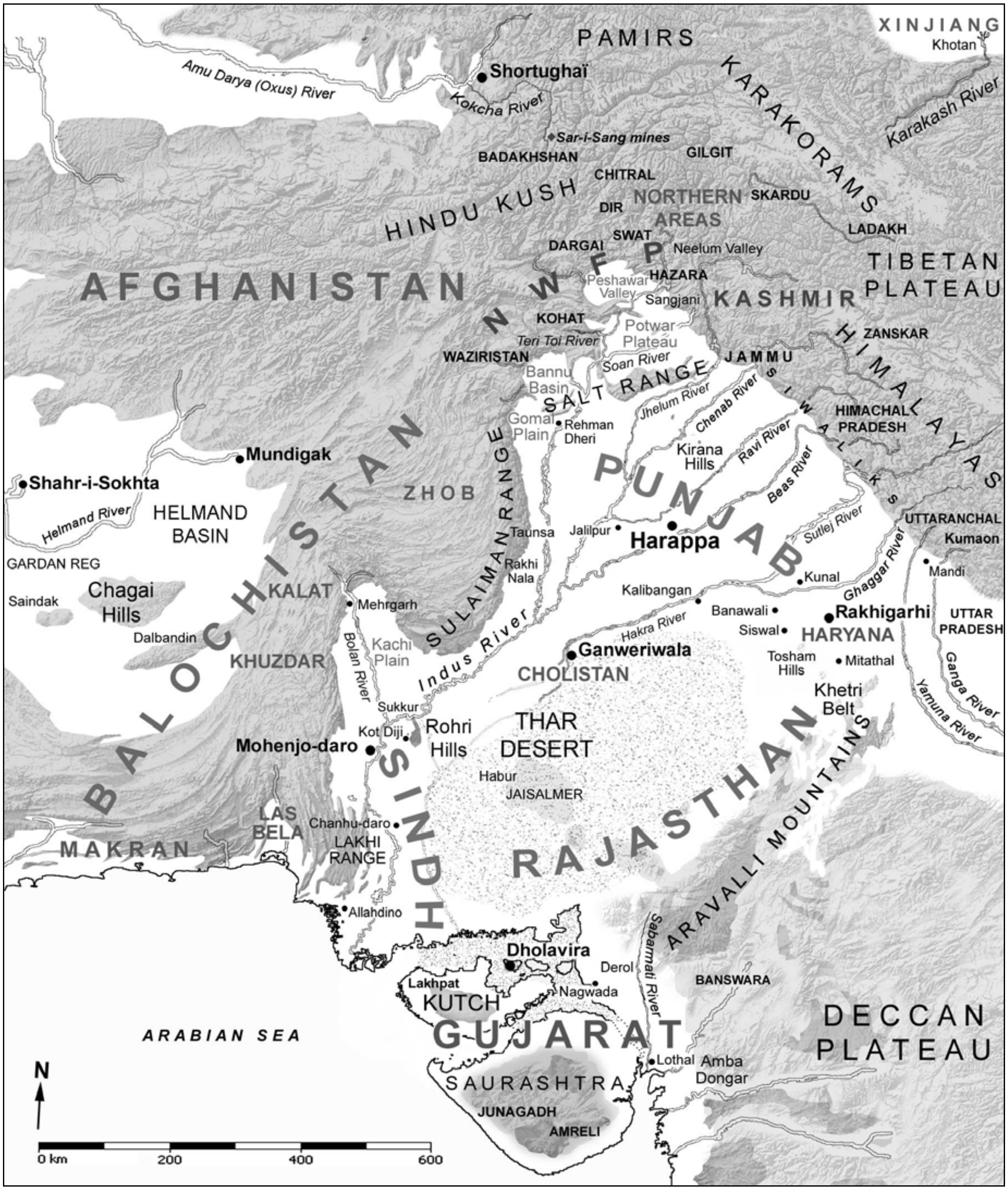
Chapter 4 – The rock and mineral artifact assemblage at Harappa

Chapter introduction – Organizing and presenting the rock and mineral assemblage

The rock and mineral artifact assemblage at Harappa is large. More than 56,000 individual items made of stone or metal have been tabulated since excavations by the HARP began in 1986. It is also very diverse. Around 40 distinct kinds of rocks and minerals are represented among the materials recovered at the site (Law 2001, Law 2005b: 113-114). The first purpose of this chapter is to organize and present this huge and highly varied body of data in a way that allows it to be examined on multiple scales. In order to make that possible, the different materials in the assemblage are placed into manageable categories that I call "varieties." Each variety is then discussed in terms of the general range of material types it encompasses, the quantities in which those materials are found at Harappa, how they are spatially distributed across the site and the chronological contexts with which they are associated. In the concluding sections of this chapter, all of that information is evaluated and then used to address one of the stated aims of this dissertation, which is to examine Harappa's rock and mineral assemblage as a single entity composed of many different elements that may vary over space and time.

The eight chapters that immediately follow this one each focus on identifying the acquisition networks of one particular rock and mineral variety used at Harappa. The second, but no less important, purpose of this chapter is to provide pertinent details on the remaining varieties in the assemblage, which are not featured elsewhere in the dissertation. Although these other varieties are not presently the subject of geologic provenience studies, simply identifying where in the Greater Indus region (Figure 4.1) they do and do not occur

Figure 4.1: Regions, sources and sites discussed in this chapter.



provides valuable information regarding the probable extent and direction of Harappa's rock and mineral acquisition networks during the chronological phases from which they were recovered. Doing this also helps to draw attention to specific regions and/or types of geological formations from which multiple varieties of rocks and minerals may have been derived. Although the results of the geologic provenience studies conducted for this dissertation sometimes indicate a certain material variety or varieties probably came from a particular region, it is useful to know what other rocks and minerals found at the site were available in that region and may have also come from that region.

The final purpose of the chapter is to provide details relating to the identification or characterization of certain rocks and minerals in the assemblage. Many material varieties could be easily identified on the basis of their macroscopic appearance alone. For others, however, some sort of assessment of their physical properties, whether by using a simple method (such as specific gravity or hardness testing) or a more sophisticated one (XRD or EMPA), was required. Also, the nature and correct identification of a few varieties of stone in the assemblage has been (and will probably continue to be) debated. The characterizations made here can at least help to narrow down the probable material types of those varieties and their likely geologic source(s).

Determining the composition of the rock and mineral artifact assemblage

The first task was to determine the composition of Harappa's rock and mineral artifact assemblage by establishing exactly what kinds of stone are present at the site and in what quantities. To accomplish this, three information sources were used: tabulation data, the Harappa database and examinations and analyses conducted specifically for this study.

Almost every artifact recovered at Harappa has been individually examined by HARP co-director Dr. Mark Kenoyer and, based on its material and/or technological attributes, placed into a *tabulation database* that he and Dr. George Dales developed with input from other project members (Meadow and Kenoyer 1992). As of 2005, this database contained 125 categories for objects made of stone or metal. For certain categories, the description of a tabulated artifact's material type is very explicit, such as those in which a "gold bead" or an "unmodified chert flake with 100% cortex" would be placed. Other categories are necessarily more generalized, such as the one for "truncated conical amulets," which are known to be made of any number of materials, not all of them stone.

When an artifact's material type was not determinable using tabulation data alone, the *Harappa database* was turned to. This FileMaker Pro database, which was developed by HARP member Sharri Clark and is maintained by HARP director Dr. Richard Meadow, contains a wealth of information relating to excavated materials including photographs of many objects, a data entry field listing specific material types and a field for descriptive entries that frequently provide additional information on an artifact's physical attributes. Material descriptions entered into this database were taken directly from the artifact recording sheets used by Mark Kenoyer as he examined objects after excavation and/or conservation. Material type for objects such as truncated conical amulets could usually be gleaned from this source. However, the Harappa database was not developed until the mid-1990s and updating it is an on-going and time-consuming process. Priority is given to registered objects and those accessioned into the Harappan Museum. Many artifacts, especially those from early excavation seasons at Harappa, have not yet been added to it.

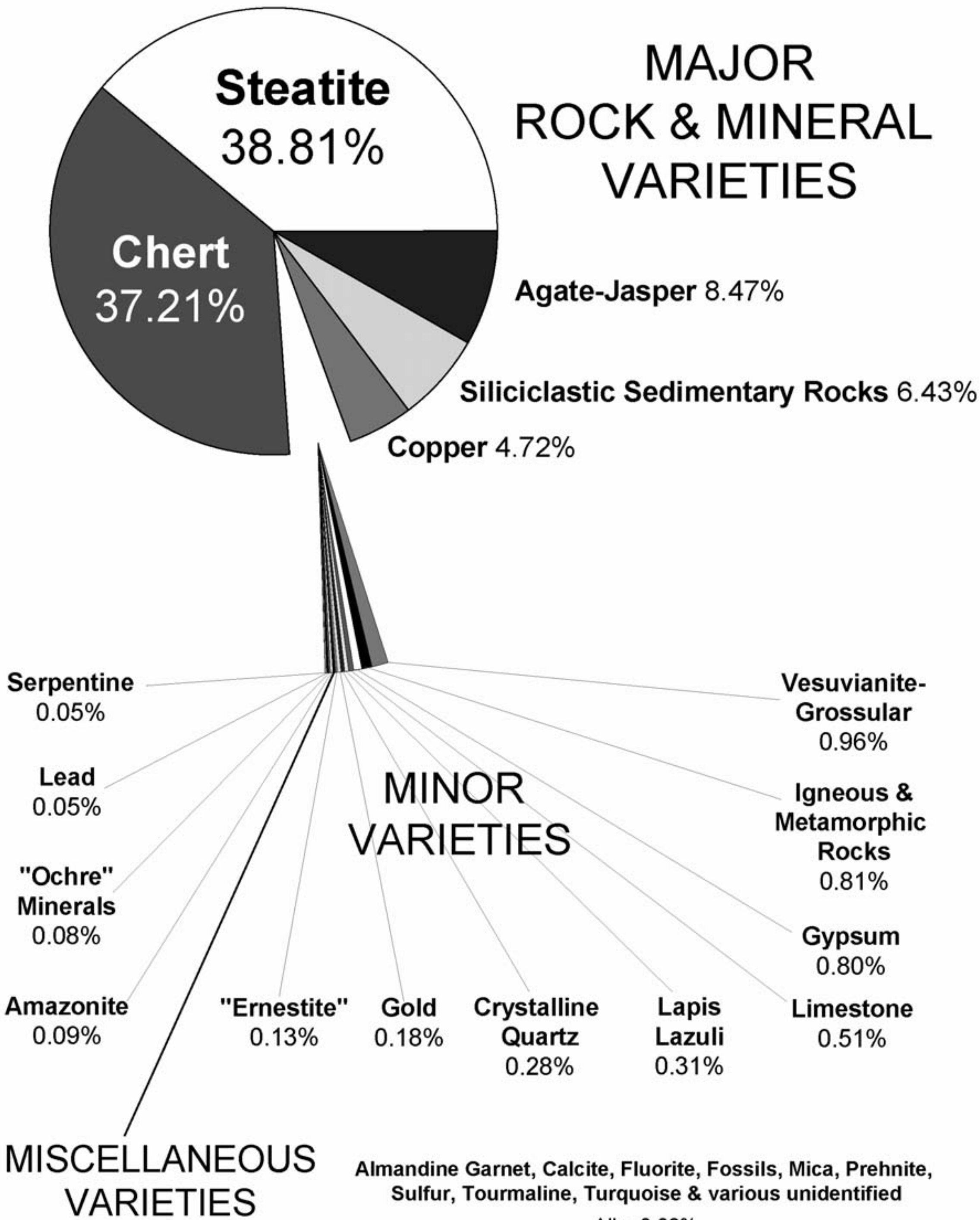
In those instances where material type could not be determined using the tabulation database or the Harappa database, artifacts were examined first-hand and categorized based on information gained from either visual inspection or one of the analytical methods employed in this study. More than 100 examples were characterized using X-ray diffraction (XRD) analysis. Whenever possible, artifacts subjected to this destructive technique were chosen from among the large sets of materials recovered during surface surveys. Appendix 4.1 lists the major mineral phases for all samples characterized in this way, as well as some minor phases detected using electron microprobe analysis (EMPA). Rather than displaying the XRD peak profiles obtained for each of the 100 plus samples (a large portion of which are absolutely identical), scans representative of the various material types (and sub-types) that were identified are provided in Appendix 4.2. Some artifacts were characterized using EMPA or specific gravity testing. Those results are presented in the body of the text of this and subsequent chapters.

After all information on material types was gathered, it was decided that the artifacts should be re-categorized in a way that would help to make a very large dataset more manageable, but still highlight the assemblage's diversity and patterns of material usage within it. They were therefore re-organized into groups that I call “varieties.” The majority of varieties still feature single material types, such as lapis lazuli or amazonite, which are macroscopically and mineralogically distinctive. Others varieties, however, were created by lumping or splitting material types. For example, rocks known as microcrystalline silicates, although mineralogically alike (all are basically quartz), exhibit enormous macroscopic variability and could have easily been divided into a dozen separate

varieties. In the end, however, only two were defined – cherts and agate-jaspers, which were based not only their macroscopic differences but also on their functional attributes (more on this below). In other instances, several rocks or minerals types were lumped together based on a shared attribute, such as in the case of "lead," which includes finished lead artifacts as well as the various raw ore sulfides, oxides, of carbonates of lead found at Harappa. Admittedly, many of choices made when defining varieties were somewhat subjective and groupings could have been made any number of other ways. However, for the purposes of this study they are quite suitable.

With the varieties of rocks and minerals defined, percentages of each one present in the assemblage were generated based on the number of individually tabulated artifacts. A chart depicting the overall composition of Harappa's rock and mineral artifact assemblage can be seen in Figure 4.2. All material varieties that compose more than 1% of the overall assemblage are defined as one of the *major* rock or mineral varieties. All those for which there are more than ten examples in the assemblage, but that make up less than 1% of the overall total, are defined as the *minor* varieties. *Miscellaneous* rock or mineral varieties are those for which ten or fewer examples have been recovered at Harappa. The designations *minor* and *miscellaneous* do not necessarily mean that Harappans considered those materials to be less important, less desirable or less requisite than any of the more abundant stone types in the assemblage. On the contrary, it is probable that many of the less common varieties were highly valued. A material such as gold almost assuredly was. Differences in the relative abundances of the rock and mineral types might be due to

Figure 4.2: The composition of Harappa's lithic assemblage. Percentages based on 56,350 tabulated rock and mineral artifacts.



recycling or re-use of certain materials and not others, variations in the amount of debitage produced when possessing different types of stone, or any number of other factors besides or in addition to frequency of use.

Major rock and mineral varieties

Over 95% of the artifacts in Harappa's rock and mineral assemblage are composed of one of five varieties of stone. These are referred to as the *major* varieties (Figure 4.3). Examples of each major variety have been recovered in abundance on every mound, in almost every excavation trench and from every chronological phase at Harappa.

Steatite

Nearly 40% of all lithic artifacts from Harappa have been classified as *steatite.* Full details regarding the origin, potential sources, geologic provenience and use of this stone during the Indus period are presented in Chapter 7. Here, I discuss the issues relating to the identification and classification of this material at Harappa.

Commonly known as "soapstone," steatite is a "soft" (Mohs' scale hardness of 1 to 2.5) metamorphic rock that is primarily composed of the mineral talc (hydrous magnesium silicate) but may contain a wide range of secondary minerals. Its visual appearance is highly variable. The color in a single hand specimen can grade from deep black to pure white with intermediate shades of red, green or yellow. Because it often resembles other soft stones such as chlorite or serpentine, misidentifications can and do occur. For example, "intercultural" style stone vessels from the third millennium BC site of Tepe Yahya in southeastern Iran were thought to be made of steatite until Philip Kohl (1976, 1979) examined them using XRD and determined that most were actually composed of chlorite.

Figure 4.3: Major rock and mineral varieties at Harappa



A. Steatite artifacts. *Top row* - fragments of raw (unheated) steatite debris *Bottom right* - heat treated steatite beads



B. Three main types of chert at Harappa *Left to right* – tan-gray (1-3) and tan-gray *banded* (4), black-brown (5-8) and purplish (heated?) chert /chalcedony (9 & 10).



C. Agate and jasper debris representing just a few of the macroscopically distinct types present at Harappa.



D. Siliciclastic rock artifacts. *Left to right*- Coarse to medium grained sandstone quartzite quern, siltstone and slate whetstones, various silicified quartzite and fine grained pebbles and cobbles.



E. Copper artifacts. *Left to right* – copper alloy rod fragment, copper alloy lump, chalcocite and malachite.

Stone artifacts classified as steatite at Harappa often differ greatly in appearance (Figure 4.3 A). For this reason, the mineralogical characterization of a sample of artifacts representative of the different visual types found there was considered to be essential.

Vidale and Bianchetti (1997) were the first to characterize steatite artifacts from Harappa using XRD. They found that four green-colored fragments were all predominantly composed of talc with occasional secondary phases of quartz or dolomite. For this study, an additional 29 unmodified (not heat treated) fragments of soft stone from Harappa thought to be steatite were analyzed using XRD (Appendix 4.1). Samples were chosen to represent the full spectrum of visual types present at the site (see Figure 4.3 A *top row* for a selection of these). Three representative XRD scans can be seen in Appendix 4.2. Scans for 20 of the samples displayed diffraction peaks for talc alone (Appendix 4.2 A), five showed talc with a minor component of dolomite (Appendix 4.2 B) and four indicated talc with a minor component of quartz (Appendix 4.2 C). Despite their variable appearances, all samples could be characterized as steatite. These results and those of the earlier study provide confidence that artifacts of this variety have been correctly classified.

It is important to note, however, that around 86% of the almost 22,000 steatite artifacts at Harappa have been heat-treated (four heated-treated steatite beads can be seen in Figure 4.3 A *bottom right*). The talc that such artifacts were originally composed of has wholly or partially converted to the mineral *enstatite* (magnesium silicate). In some cases heating may have also resulted in the formation of *cristobalite* (SiO_2). Cristobalite is a high temperature *polymorph* (polymorphs are two minerals sharing the same chemical composition but having different crystal structures) of quartz. A full discussion of this

process can be found in Chapter 7. Although the original mineral compositions of these heated artifacts have been considerably altered (technically making them a different mineral – enstatite), for the purposes of this study they are still classified as steatite.

Microcrystalline silicates

Chert, flint, jasper, chalcedony, agate, carnelian, bloodstone, heliotrope chrysophrase, novaculite, radiolarite, sard and onyx are all terms for closely related (in many cases mineralogically identical) sedimentary rocks. All are composed principally of microscopic crystals of quartz (either granular or fibrous) that form when silica chemically precipitates out of an aqueous solution (Luedtke 1992: 18). Numerous visually distinctive types of microcrystalline silicates are found at Harappa and, when considered in total, they are the most abundant variety of lithic material at the site. However, I have chosen to divide this diverse assemblage into two, albeit still broad, sub-varieties – cherts and a combined category consisting of agates and jaspers (agate-jasper). This division makes chert a close second and agate-jasper a distant third in terms of abundance of tabulated stone artifacts at the site. The decision to define two sub-varieties was based partially on the different macroscopic characteristics of microcrystalline silicates (described below) and partially on the different uses Harappans made of such materials. Chert was used mainly as a material for making tools and cubical weights. Agates and jaspers were primarily stones from which ornaments (mostly beads and pendants) were fashioned. Although some ornaments and other objects made of chert have been recovered at Harappa and numerous agate-jasper tools have also been found (notably in the site's earliest phase), the two material sub-varieties were *typically* used for creating different types of objects.

Chert

No hard and fast definition exists for the term "chert." Barbara Luedtke (1992) used it in a general way to refer to all microcrystalline silicates. She considered agate, for example, to be a translucent variety of chert (ibid.: 31). George Rapp (2002: 71-72) prefers to differentiate microcrystalline silicates based on their crystal structures – cherts are those with a granular structure while chalcedonies have a fibrous structure. At Harappa, classification has been based mainly on visual characteristics. Chert artifacts are generally defined as those opaque microcrystalline silicates having a color that is either neutral (ranging from light gray to black) or a shade of brown. The one exception to this convention is a type of chert/chalcedony with a purplish hue that was used to make tools during the Early Harappan periods. Artifacts fitting these descriptions make up over 37% of the rock and mineral assemblage. Examples of the three most common macroscopic types – tan-gray (sometimes banded), black-brown and purplish chert/chalcedony can be seen in Figure 4.3 B. Chapter 6 is devoted to examining the acquisition of these chert types.

Agate-Jasper

If you ask a geologist, mineralogist, gemologist and archaeologist each to define agate and jasper you may very well receive four different answers. The lack of consensus is mainly due to the fact that these types of microcrystalline silicates are so highly variable that they defy any absolute classification (Butler 1995). For this reason, it was decided that the criteria used in this study should be as straightforward as possible. Agates are simply defined as any wholly or partially translucent variety of microcrystalline silicate. Jaspers are those opaque microcrystalline silicates that are of colors other than the ones used above

to define chert – generally this means shades of red, green or yellow. In Gujarat and again in Waziristan, I have seen microcrystalline silicates that grade from jasper to agate in an individual hand specimen. When considered as a single material variety (for reasons explained), agate-jasper comprises 8.47% of the site's rock and mineral assemblage. Not surprisingly though, the use of such broad, encompassing definitions means that artifacts in this category vary tremendously in their visual appearances (Figure 4.3 C).

Although defined here as belonging to the "agate-jasper" sub-variety, some jasper artifacts are dealt with (briefly) in the chapter on chert (Chapter 6). In Chapter 8, INAA is used to compare agate from sources (or proxy sources) in India and Iran to a set of archaeological samples from Harappa and several other prehistoric sites in South Asia.

Siliciclastic sedimentary rocks

"Siliciclastic" rocks are those composed of *clastic* sediments (materials weathered or broken from pre-existing rocks) primarily derived from *silica*-rich, non-carbonaceous rocks. Rocks of this variety include conglomerate, sandstone, siltstone, greywacke, mudstone and shale. *Quartzites* form when the clastic sediments composing such rocks recrystallize to varying degrees due to heat and/or pressure. Although therefore technically a metamorphic rock, quartzite is included in this material variety as it is defined here.

Roughly 3600 siliciclastic sedimentary rock artifacts make up between 6 and 7 percent of Harappa's lithic assemblage. Over 70% of these are grindingstones – querns, mullers, mortars or pestles, which are typically composed of sandstone/quartzite (Figure 4.2 D *left*). The potential geologic sources of those rocks and the acquisition networks through which they were brought to Harappa is examined in Chapter 5.

Multiple types of sandstone, quartzite, greywacke, siltstone and mudstone were used to create the artifacts comprising the remaining portion of this material sub-assemblage, which includes implements like whetstones and burnishers as well as a variety of non-utilitarian items such as beads, amulets, cubical weights, balls, "gaming" pieces and small ringstones or mace heads. Determining the geologic provenience of artifacts composed of such common but variable stone is difficult to do beyond the regional level at best. Whetstones (used for sharpening edged tools), for example, were typically made from compact fine-grained sandstones or siltstones (Figure 4.2 D *center*). Although such rocks occur in numerous regions surrounding the northern Indus Basin, the various sedimentary sequences of the Sulaiman Range (Shah 1991) – 225 km directly west of Harappa, would have been the source of the most abundant and best quality material for this type of artifact (*personal observation*).

Several hundred whole and fragmentary siliciclastic pebbles (4 to 64 mm in size) and cobbles (64 to 256 mm) of various descriptions (Figure 4.2 D *right*) have also been found at Harappa. These could have come from *almost* anywhere. Water-rounded stones of all sizes, textures and colors are found in many of the Miocene-Pliocene Siwalik and later Quaternary sedimentary formations that run along the entire western and northern margin of the Indus Basin (Cheema et al. 1977: 89-98) as well as in the beds of rivers draining the highlands surrounding the Punjab Plain (*personal observations*). Those rivers, however, could not have carried these stones very far out onto the plains. All pebbles or cobbles found at Harappa, no matter how small, had to have been intentionally transported several hundred kilometers to the site.

Copper and copper minerals

The production of copper or copper alloy objects is the hallmark of *Chalcolithic* or Bronze Age societies in the Old World. For the purposes of this study, the material variety *copper* includes artifacts that are composed of processed copper metal as well as raw copper minerals. Throughout this dissertation I refer to processed metal objects (copper and otherwise) as being part of the Harappa's rock and mineral assemblage, although it is recognized that such artifacts are, technically, neither rocks nor minerals. Like heat-treated steatite, the original nature of material composing metal objects has been significantly altered. However, unless made from native metal, most were originally derived from a metalliferous rock or mineral and so are classified as such.

At Harappa, copper artifacts make up less than 5% of the site's rock and mineral assemblage. It might appear then that use of this material, although noteworthy, was somewhat limited – especially in relation to a much more abundant material like chert. However, unlike chert, metal objects and scraps that are no longer considered useful can be collected, recycled and re-used indefinitely. The copper artifacts at Harappa that escaped recycling and entered the archaeological record almost assuredly under-represent, to a significant degree, the amount of metal that actually was used at the site.

Although most copper artifacts at Harappa (Figure 4.2 E) are either identifiable copper alloy objects or non-descript fragments, a handful of raw copper ores have been found. Using XRD these have been identified (Appendix 4.2 D & E) as *chalcocite* (copper sulfide) and *malachite* (copper carbonate hydroxide). The potential sources and possible geologic provenience (s) of these ores are investigated in Chapter 12.

Minor rock and mineral varieties

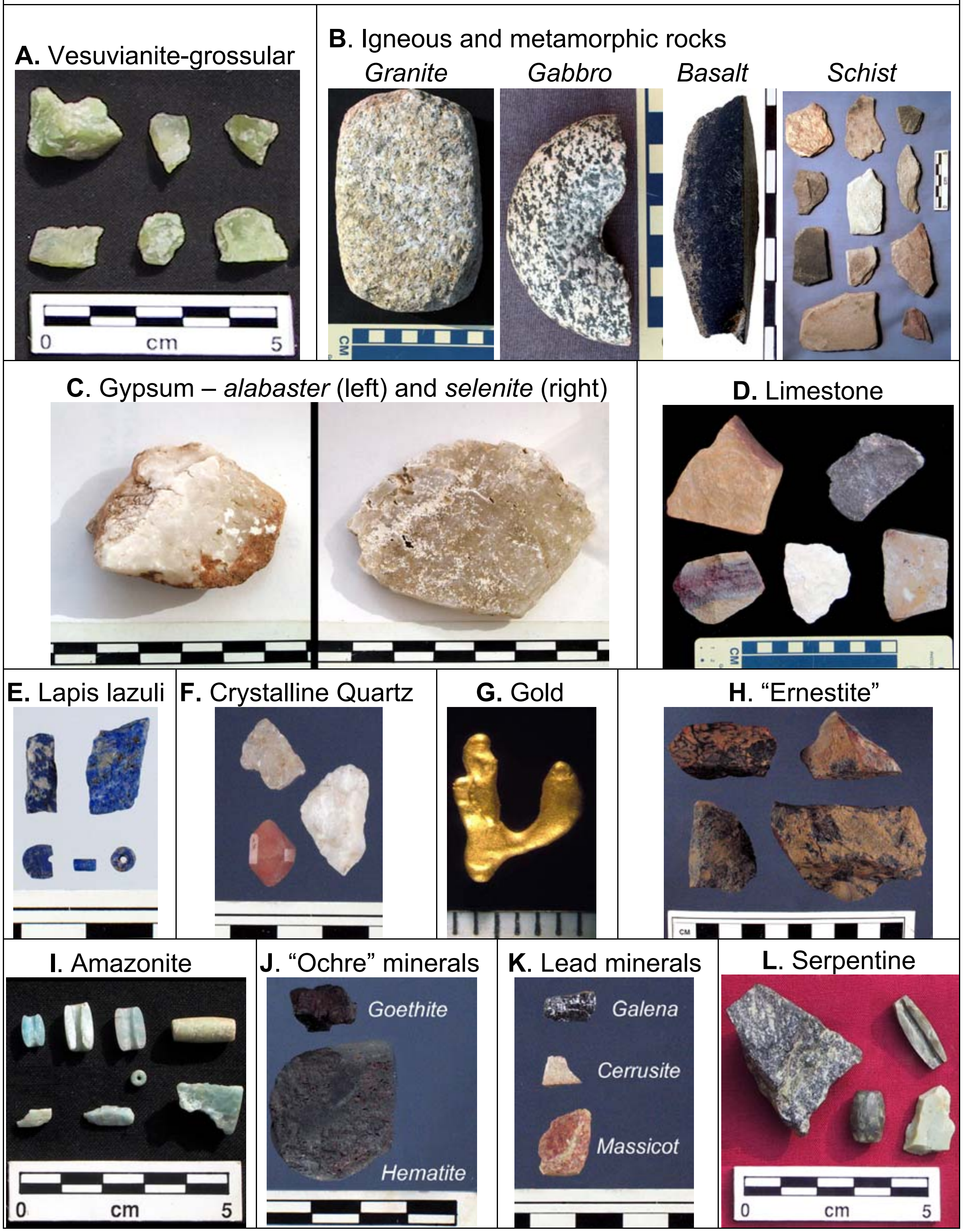
Twelve materials make up most of the remaining 4.36% of Harappa's rock and mineral assemblage. These *minor* rock and mineral varieties (Figure 4.4) are presented below in order of their decreasing overall abundance in the assemblage.

Vesuvianite-Grossular

Chapter 9 is entirely devoted to examining the potential sources and probable geologic provenience(s) of vesuvianite-grossular garnet – a hard (6.5 to 7.5 on Mohs' scale), translucent, green-colored rock (Figure 4.4 A) that, after steatite and agate-jasper, was the third most common material used by Harappans to make beads and other small ornaments. Full details relating to that stone's appearance, mineralogy and other physical properties are presented in Chapter 9. Here, I briefly discuss how this material was identified and in what contexts it occurs at Harappa.

Vesuvianite and grossular garnet are two distinct minerals, which sometimes co-occur to form a massive gem-quality rock (Anderson 1966). To date, 543 objects and fragments composed of the co-occurring variety, which I simply call "vesuvianite-grossular," have been found at Harappa. Twenty-five of the fragments (roughly 5% of the material sub-assemblage) were directly identified using XRD. Appendix 4.2 F is a composite of four of those scans, which illustrates how the rock grades from pure grossular, to a vesuvianite-grossular mix, to pure vesuvianite, to a heavily weathered (chloritized) material with only traces of vesuvianite. One hundred eighty-two artifacts (nearly 30% of the material sub-assemblage) were classified based on specific gravity (SG)

Figure 4.4: Minor rock and mineral varieties at Harappa



testing, which easily distinguishes dense vesuvianite-grossular (≈ 3.0 to ≈ 3.5) from lighter minerals like quartz or serpentine (both ≈ 2.6).

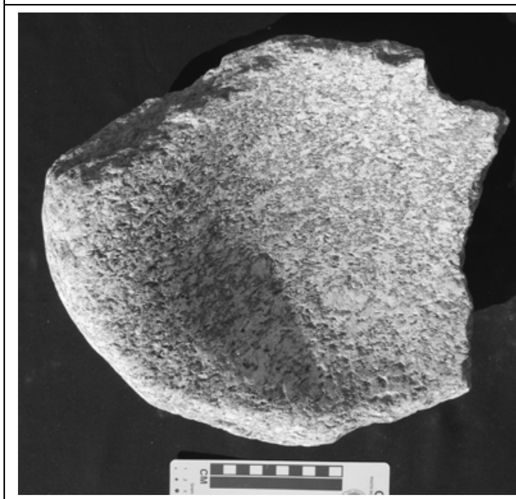
The use of vesuvianite-grossular at Harappa was largely restricted in time and space. More than 90% of artifacts made of this stone are found on conjoined mounds E-ET. Most of the remaining ones were recovered from Harappan Period refuse areas away from the main habitation mounds (e.g., the "Low Western" Mound and the debris layers above the Cemetery area). Ninety-seven percent of the total number of vesuvianite-grossular artifacts from secure stratigraphic contexts (n = 180) come from Period 3C levels. Ninety-seven percent of those are from mounds E-ET but a few examples were excavated on mounds AB, F and the Mughal Sarai area. A single flake each was recovered in Period 1 and Period 5 levels on the north side of Mound AB.

Igneous and Metamorphic rocks

A huge range of rocks are encompassed by the designations *igneous* (rocks formed from magma) and *metamorphic* (pre-existing igneous or sedimentary rocks altered by heat, pressure or chemically active fluids). Many of the "varieties" defined and described elsewhere in this chapter fall into these categories. For instance, steatite, quartzite and lapis lazuli are technically metamorphic rocks. However, for purposes of categorization, the materials that are classified as "igneous and metamorphic rocks" (Figure 4.4 B) here include a much more limited (albeit still very broad) range of material types than the two geologic terms normally encompass. The igneous variety at Harappa includes granite, andesite, rhyolite, gabbro and basalt. The metamorphic variety includes such rocks as gneiss, schist, phyllite and slate.

All together, 455 artifacts recovered at Harappa are of the “igneous and metamorphic rock” variety. Just over one-third (34%) of those are grindingstone artifacts such as querns (Figure 4.5 A), mullers and whetstones. These are discussed in greater detail in the chapter immediately following this one. Twenty-two percent are schist, phyllite or slate fragments (fourth image of Figure 4.4 B), many of which are probably pieces from flat discs (palettes?) like the example in the Harappa Museum’s reserve collection (Figure 4.5 B) that comes from excavations carried out in the 1920s and 30s. Almost 15% are small chunks and flakes of various igneous and metamorphic rock types

Figure 4.5: Select artifacts of the “igneous and metamorphic rock” variety.



A: Granite quern - Harappa Museum



B: Schist disc (palette?) - Vats’ #3734



C: Basalt cobble/“touchstone” – H2000/2194-51



D: Gabbro weight - H90/3000-17

that are probably debris from the manufacture of finished items. Many different types of artifacts make up the remaining 30%. There are basalt amulets, beads, large conical objects and cobbles that were probably used as “touchstones” (Figure 4.5 C). Gabbro was sometimes used to make cubical weights (Figure 4.5 D) and small ringstones (a broken example can be seen in the second image in Figure 4.4 B). Although some types of artifacts are found during certain periods only (truncated conical amulets made of basalt, for instance, are found only in Period 3 levels), examples of igneous and metamorphic rocks have been recovered from all chronological phases and from all parts of the site.

Harappans could have obtained the igneous and metamorphic rocks they used from any one of the numerous geologic formations across northwestern South Asia in which they are found. Using EMPA, I conducted a small characterization/ provenience study of two basalt fragments from the site (Appendix 4.3). The results indicated that those particular artifacts probably were *not* related to the continental flood basalts known as the Deccan Traps, which lay far to the south of Harappa in peninsular India and Gujarat. Although I am in no way ruling out the possibility that other basalt objects or other kinds of igneous or metamorphic rock recovered at the site could have come from those regions, here I discuss only those sources located within or directly adjacent to the upper Indus Basin.

The closest occurrences of igneous and metamorphic rocks to Harappa are situated in the northern-most of the Kirana Hills outcrops (Alam et al. 1992), approximately 140 directly north of the site, near the modern city of Sargodha. There, rhyolite, andesite, volcanic tuff, phyllite and slate are all found in the Precambrian Hachi Formation (ibid.). In Chapter 5, I demonstrate that during periods 1 and 2, residents of Harappa acquired most

of the meta-sedimentary rocks they used for grindingstones from the Kirana Hills. It is, therefore, quite reasonable to assume that some of the igneous and metamorphic rocks found at the site during those periods also may have come from this region. Approximately 70 km beyond the Kirana Hills is the Salt Range, where granite can be found in the boulder beds of the Tobra Formation (Shah 1980: 12; *personal observations*) and an area of heavily weathered basaltic rock called the Khewra Trap exists (Jan and Faruqi 1995). Cobbles of different varieties of igneous and metamorphic rock can be found in the conglomerate beds of the Siwaliks (Brozovic and Burbank 2000), which ring the western and northern margins of the Indus Basin. Around 350 km southeast of Harappa, in the vicinity of Tosham in southern Haryana (Grover and Kumar 1980; Pareek 1986), a series of igneous outcrops break the alluvial plain that may have been important potential sources for rock of this kind. Several Early Harappan, Harappan and Late Harappan Period settlements lie in close proximity (≈ 25 km) to these outcrops including the site of Mitathal (Bhan 1969, 1975). Finally, basalt, gabbro, gneiss and other dark, magnesium and iron-rich (*mafic*) igneous and metamorphic rocks can be found in the ophiolite sequences that occur at various points along the northern and western margins of the Indus Basin. Residents of the Harappan and/or Early Harappan Period sites of the Bannu Basin, Gomal Plain or far northern Balochistan would have been in the positions to acquire these types of stone from the northern Zhob or the Waziristan ophiolites.

Gypsum

The mineral *gypsum* (hydrated calcium sulfate) occurs in two forms – compact masses called *alabaster* and tabular crystals called *selenite*. Both forms have been

recovered at Harappa (Figure 4.4 C) and directly identified as gypsum using XRD (Appendix 4.2 G). In Chapter 10, the potential sources and probable provenience(s) of alabaster (the more common of the two forms) are examined in detail. Alabaster objects and/or debris fragments have been recovered in all major areas of the site and from every chronological phase and sub-phase from Period 1 through Period 3C.

Limestone

Fewer than 300 artifacts made of limestone (a sedimentary rock consisting mainly of calcium carbonate) have been recovered at Harappa. It is somewhat surprising that rock of this type is not more represented in the site's assemblage given its widespread availability around the Greater Indus region. Also interesting is the fact that few artifacts made of this material are found in levels prior to Period 3C. During Period 3C, numerous distinct types of limestone were used residents of Harappa. The physical characteristics of the five most common types (Figure 4.4 D), their potential sources, probable geologic provenience(s) and questions relating to their use at the site are examined in Chapter 11. Three additional, less common, types of limestone are briefly discussed here.

Chalk

Several fragments (one is from Period 3C levels on Mound F, the rest are surface finds turned in by workmen at Harappa) of the soft, pure white form of limestone known as *chalk* have been found at Harappa. Chalk deposits, although extensive in many parts of the world, are limited in South Asia. It is reported to exist in different parts of the Kashmir Valley (Bates 1873: 19). In Sindh, the only reported occurrences are in the upper part of the Laki Limestone formation around Thano Bula Khan in southern Sindh (Jafry and

Ahmad 1991: 61). After that, one must travel southeast to Gujarat to find this type of limestone. Large chalk deposits are found in the Junagadh District (Desai and Pathole 1979) while smaller occurrences lie near Lakhpat in Kutch (Merh 1995: 168-169).

Variegated and fossiliferous limestone

"Sang-i-Abri" (Cloud stone) is the colloquial term for a type of khaki to dark red *variegated limestone*. Just a few of artifacts (a bead and some blocks/slabs) made from this stone have been reported from Harappa (Vats 1940: 150, 177). "Sang-i-Miriam" (Stone of Mary) is a yellowish-brown to dark brown *fossiliferous limestone* that has long been used in South Asia both for decorative inlays (Figure 4.6 A) and for fashioning small ornaments. Only two artifacts have been found at Harappa made of this type of stone (Figure 4.6 B). The blocklet pictured on the right of the figure is from Period 3C levels in Trench 43, Mound F. Although the truncated conical amulet on the left is a surface find turned in by one of the workmen, it is clearly of Harappan design (numerous amulets with the *exact* same form but made of different kinds of stone have been found in Period 3 levels).

Although fossiliferous limestones occur in many formations around the Indus region, those with the macroscopic characteristics of Sang-i-Miriam seem to be quite rare (*personal observations*). Stone of this exact description is quarried today in the Jaisalmer District of Rajasthan near Habur (Figure 4.6 C) and I have seen fragments and pockets of a very similar looking variety near the site of Dholavira on Khadir Island, in northern Kutch, Gujarat (Figure 4.6 D). In the museum of the Geological Survey of Pakistan-Quetta there is a polished slab of Sang-i-Miriam said to be from Sangjani in the Rawalpindi District, Punjab. The two artifacts from Harappa might have come from any one of these sources.

Lapis Lazuli

Most of the 174 lapis lazuli artifacts recovered during HARP operations are beads, unfinished beads and fragments of manufacturing debris (Figure 4.4 E). Examples have been found on every mound at the site and from all of its chronological phases and sub-phases (Appendix 4.4 *Figure 2*). Lapis lazuli is a rock that may contain varying amounts of several minerals including calcite and pyrite, but it is *lazurite* (sodium calcium aluminum silicate sulfur sulfate) – a mineral isomorph of haüyne and sodalite – that provides the stone with its characteristic blue color (Leithner 1975; Hogarth and Griffen 1976a; Webster 1994: 263). Although other blue-colored minerals, such as azurite and sodalite, are sometimes mistaken for lapis lazuli, in most cases it is sufficiently distinctive so that an experienced individual may confidently identify it based on visual inspection alone. That is, if one has looked at enough genuine examples it is generally easy to spot (based on hue, luster, crystal habit and visible mineral associations) a different stone for which the blue color is probably not due to the presence of lazurite. Still, misidentifications can be made. Shaffer reported (1982: 193) that Walter Fairservis had analyzed "lapis lazuli" samples from several Indus Civilization sites including Mohenjo-daro and found them to actually be the mineral *azurite* – a hydrated copper carbonate with a brilliant blue color. So to be on the safe side a few of the more ambiguous-looking debris fragments from Harappa were analyzed using XRD (see Appendix 4.2 H for an example of one of those scans). The primary mineral phase in those samples was most definitely lazurite and I am quite confident that all other artifacts from the site that are classified as lapis lazuli are actually made from this stone.

In Appendix 4.4, I examine in detail the question of where the lapis lazuli used by residents of Harappan and other Indus Civilization peoples originated. I have come to the conclusion that, given all of the evidence that is presently available, the Sar-i-Sang area mines in the Badakhshan region of northern Afghanistan would have been the *only* viable sources of that stone. Lapis lazuli is therefore one of the few materials found at Harappa (the others being marine shell and the remains of oceanic species of fish) that provides unequivocal evidence for both the direction and extent of long-distance acquisition networks during the periods in which they are present.

Crystalline quartz

Quartz (silicon dioxide) is the most abundant substance in the earth's crust after feldspar (Deer et al. 1992: 469). Making a firm statement regarding the possible geologic proveniences of artifacts made from such a commonplace mineral is therefore problematic. It is possible to say that the crystalline varieties of quartz found at Harappa (Figure 4.4 F) usually (but not always) occur in association with igneous or metamorphic rocks (Pough 1988: 220-221). The 160 crystalline quartz artifacts recovered include beads or fragments of clear "rock crystal", "smoky" quartz, "milky" quartz, "rose" quartz and pink-colored bi-pyramidal crystals known as Mari "Diamonds." Nearly half (79 of 160) of these come from stratified contexts representing all periods and sub-periods from 2 through 3C. The majority (78%) of those that date to Period 3C and although they were recovered from each of the site's mounded areas as well as the cemetery area dump, the heaviest concentration (56% of the total for this period) were found in Trench 43 on Mound F.

The quartz crystals known as Mari "Diamonds" are highly distinctive and, because they were very likely derived from alabaster deposits in the Salt Range, they are discussed in the portion of this dissertation (Chapter 10) featuring the alabaster provenience study. All or some of the remaining kinds of crystalline quartz at Harappa can be found (usually in granitic rock) in numerous parts of the Greater Indus region. Such areas where occurrences are found lying within or directly adjacent to the upper Indus Basin include the Kirana Hills (Heron and Crookshank 1954: 131; *personal observations*), the Northern Areas of Pakistan (Kazmi 1995b: 288), Himachal Pradesh (Geological Survey of India 1989a: 47), southern Haryana (Geological Survey of India 1989b: 34) and northern Rajasthan (Department of Mines and Geology 1989: 48-49; *personal observations*).

Gold

Artifacts made of gold (mostly small beads and leaf or foil fragments) have been found on every major mound at Harappa. Approximately half of the 120 examples recovered come from securely dated strata spanning Period 1 through Period 3C. The other half are from surface or disturbed contexts and, therefore, it is possible that at least some of those were originally deposited in Late Harappan levels that were subsequently disturbed. The best evidence for gold-working at the site comes from Trench 54, where a gold droplet[1] (Figure 4.4 G), small crucibles, a basalt touchstone (used in modern gold bazaars to test the purity of an item by observing the streak it leaves on the stone's black surface) and an unusually heavy concentration of gold beads and fragments were found in deposits eroding from Period 3B and 3C levels (Meadow et al. 2001: 14-15).

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[1] this gold "droplet" may actually br a tiny placer nugget (J.M. Kenoyer *personal communication* 2001)

The number of gold objects that have been found at Harappa and other Indus Civilization sites almost assuredly represents but the tiniest fraction of what was actually used. Any amount of the precious metal left over from the manufacture of finished items no doubt would have been scrupulously recovered and recycled, just as it is by modern goldsmiths in South Asia (or anywhere else for that matter). Also, in contrast to practices in other contemporaneous Old World civilizations, Harappans generally were not inclined to inter their dead with much in the way of wealth items (made of precious metals or otherwise). Although a few gold artifacts have been found in graves at Harappa (Dales and Kenoyer 1989a: 89, 91), most were apparently kept in circulation rather than permanently buried. Precisely how much was in circulation is difficult to estimate, but finds of jewelry hoards, such as those unearthed at Harappa (Vats 1940: 63-66) and Mohenjo-daro (Mackay 1931c: 522-524), suggest that the amount was probably substantial. Recently, the Archaeological Survey of India recovered ten kilograms of gold and silver ornaments from a hoard, which that had already been heavily looted, at the Late Harappan site of Mandi in western Uttar Pradesh (Sharma et al. 2000; Tewari 2004).

Where did Harappans obtain gold? There are many possibilities as it is a metal with a remarkably wide distribution across South Asia – a fact noted by Sir Edwin Pascoe when he discussed (1931: 674-675) the possible geologic sources for the gold artifacts found at Mohenjo-daro. Comprehensive and reasonably up-to-date accounts of the many occurrences, both major and minor, in Pakistan and India already exist (Ahmad 1969: 23-25; Nanda 1992; Radhakrishna and Curtis 1999; Shams 1995b: 240-243; Ziauddin and Narayanaswami 1974) and so only the most pertinent regions or occurrences are reviewed

here. The Kolar gold fields of southern India have been the most productive in modern times (Wadia 1975: 444) and some scholars have proposed that Indus Civilization consumers may have obtained this precious metal through long-distance interaction with the Neolithic cultures of that region (Agrawal 1984: 165; Allchin and Allchin 1997: 102; Bhardwaj 1989: 327; Ratnagar 2004: 156; Rao 1985: 632-33). Although this is certainly a possibility that should not be dismissed, the goldsmiths of Harappa were in much closer proximity to other regional sources of that metal, three of which I discuss below.

A substantial portion of the gold produced in the modern world comes from *porphyry copper* deposits (copper mineralized in association with intrusive igneous rocks) that are rich in noble metals (Kesler 2004; Sillitoe 1979). The Khetri copper belt of northwestern Rajasthan is one of these deposits. Both gold and silver are recovered at the Hindustani Copper Ltd. smelting plants operating in this region today (Rao et al. 1997). If the Khetri belt was one of the major sources for the copper used by Indus Civilization peoples as has been proposed (Agrawala 1984), then some Harappan gold may have been derived from northwestern Rajasthan. Gold is also currently being recovered from porphyry copper deposits in the extreme western part of Balochistan around Saindak (Lamb 1988; Mining Magazine 2001; Shams 1995b: 241; Wolfe 1974). Ancient workings and smelting areas can be found throughout that region (Vredenburg 1901) and into eastern Iran (Bazin and Hübner 1969: 153-157). Immediately to the north, in the Gardan Reg region of southwestern Afghanistan, immense spreads of copper production debris were found in association with graves and ceramics dating to the third millennium BC (Dales and Flam 1969; Dales 1992; Fairservis 1961; Vredenburg 1901: 264-265). George Dales

reported (1992: 26) that the analysis of a copper slag sample from Gardan Reg indicated that its "gold assay was very high, high enough to be commercially valuable."

The closest and most "obvious" sources from which residents of Harappa may have obtained gold, however, are the myriad rivers and streams that drain the mountain ranges north of the upper Indus Basin (Kenoyer and Miller 1999: 120). To this day, "gold-washers" work the placer deposits of the Indus and other rivers in the far north of Pakistan (Ahmad et al. 1975; Khan 1999; Tahirkheli 1960), the Soan (Gold) River and several of its tributaries on the Potwar Plateau (Heron and Crookshank 1954: 79), tributaries of the Jhelum river (Ahmad 1969: 25), the Beas River and other numerous other smaller streams in Himachal Pradesh (Director - Punjab Haryana and Himachal Pradesh Circle - Geological Survey of India 1971), the Sutlej drainage basin (Ruby 1998) and the Siwaliks at the base of the western Himalayas (Lal et al. 1985). Although occurrences there have been characterized as "meager" (Ahmad 1975: 176) and barely profitable for those working them in the modern era (Wadia 1975: 445), historical accounts from the Greek through the Mughal periods suggest that the mountainous regions and rivers of north of the Punjab were, in former times, major sources for gold (for discussions of the many literary references to gold from this region see Biwas 1996: 327-328; Nanda 1992; Peissel 1984; Ratnagar 2004: 156-157). I would even submit that a phenomenon not unlike a "gold rush" could have taken place in this area during the later prehistoric period.

Gold rushes of eras past (Green 1993; Morrell 1941) all played out in the same basic way. Rich, previously unexploited deposits were discovered and all of the easy-to-recover metal was quickly consumed. After the initial "rush," gold became progressively

more difficult to extract and the sources were abandoned or worked on a greatly reduced scale. The first gold artifacts in northwestern South Asia appear during the latter half of the fourth millennium BC in the Punjab, at Harappa and at Jalilpur (Mughal 1972b: 119). From this time forward, the precious metal is a constant feature in the archaeological and historical records of that region (Nanda 1992). It is therefore entirely possible that sources north the Punjab have been *continuously* exploited for more than 5000 years. The amount of gold recovered in the modern era is, in all likelihood, a pale reflection of what may have existed at the time sources there initially were worked. Consider the mid-19th century AD gold rush of northern California in the western United States. A survey of that region today would likely provide little indication of the incredibly rich alluvial deposits that once existed there and which, in a mere two decades, were largely exhausted (Clamage 1998). I am not necessarily suggesting that the deposits north of the Punjab were similarly rich or that a "rush" of the same scale or intensity as California's took place in northwestern South Asia during the Harappan Period, only that we should not evaluate the potential of this region as a gold source based on the amount of metal that is being recovered there today.

Admittedly, no material evidence has ever been found in regions north of the Punjab that would indicate that gold was being exploited there during the prehistoric period, nor is it ever likely to be. Ancient gold-washers would, quite obviously, have had little or no archaeological impact and it is highly unlikely that camps or settlements associated with such activities would be persevered in a dynamic mountainous environment like the Himalayas. The notion of a Harappan Period "gold rush" in this region is entirely hypothetical. It is, however, a hypothesis that eventually can be *tested*. There is every

reason to expect that it might be possible to differentiate alluvial gold derived from sources in northwestern South Asia from that originating in the Precambrian rocks of South India, the gold-rich copper ores of Rajasthan or Balochistan, or from sources elsewhere. Geochemical comparison of Harappan gold artifacts with geologic samples collected from these regions is certain to be an important and productive area of inquiry in the future.

"Ernestite"

"Ernestite" is the name given by Kenoyer and Vidale (1992) to an extremely fine-grained khaki-colored stone that is mottled with dark-brown to black patches and dendritic veins (Figure 4.4 H). It is a hard (Mohs hardness of at least 7), very tough (does not break or fracture easily) and fairly dense stone (SG ranging from ≈ 2.8 for the khaki-colored matrix to ≈ 3.2 for the brown-black portion). At Harappa and other Indus sites where it has been identified, such as Mohenjo-daro, Chanhu-daro and Dholavira, "Ernestite" was fashioned into small constricted cylindrical drills, which were used by beadmakers to perforate hard materials (namely microcrystalline silicates and vesuvianite-grossular). Using XRD and EMPA, Kenoyer and Vidale (1992) characterized it as an unknown variety of metamorphic rock composed of quartz, sillimanite-mullite and hematite-titanium oxide phases (ibid.: 506-507). Recently, however, I have conducted a series of follow-up analyses that instead suggest "Ernestite" is a type of *indurated tonstein flint clay* that has been deliberately heated to produce or enhance properties that made it a highly effective material for drilling hard stone beads. In Appendix 4.5, I provide full details on how I came to those conclusions and discuss the possible geologic sources from which Harappans may have acquired the original raw material.

The utilization of "Ernestite" at Harappa was limited in space and time. All but a handful of the roughly 75 drills, drill rough-outs and debris fragments found to date come from the conjoined area of mounds E-ET. Most of those that do not were found in Harappan period dump debris or surface contexts away from the site's main habitation areas. Thirty-eight of the 40 "Ernestite" artifacts recovered from secure contexts came from Period 3C levels while the remaining two were from Period 3B strata. Interestingly, these temporal and spatial patterns seem to closely mirror those for vesuvianite-grossular – a rock that can have a Mohs hardness greater than 7 depending on its grossular content. It is probably no coincidence that stone of that variety is mostly found *when* and *where* beadmakers were also using "Ernestite" because "Ernestite" was the only material available from which drills capable of perforating it could be made (this association is discussed further in Chapter 9). Diamond was not available at this time and the microcrystalline silicate drill bits that Harappans used for other types of stone would have would have been wholly ineffective (explained in Appendix 4.5) on vesuvianite-grossular as well as the long style of carnelian beads. "Ernestite" drills represented a major technological innovation.

Amazonite

The variety of the feldspar mineral *microcline* (potassium aluminum silicate) known as *amazonite* is easily recognized by its prominent cleavage face in combination with its characteristic white-green to blue-green appearance. Despite being one of the less abundant minerals at Harappa, examples have been recovered on each major habitation area at the site except Mound E and from every occupational phase except Period 3A. A selection of amazonite beads and manufacturing debris can be seen in Figure 4.4 I.

Amazonite, sometimes referred to in the literature as “green microcline,” occurs in *pegmatites* (Deer et al 1992: 425-426). Pegmatites are zone of unusually coarse-grained igneous rocks that are important sources of rare elements and semi-precious minerals (including several in Harappa’s assemblage). Early researchers speculated that amazonite artifacts from Mohenjo-daro may have come from a source in the Nilgiris Range of southern India (Pascoe 1931: 678; Mackay 1938: 500). However, this purported occurrence was long ago shown to probably not exist (Gordon 1935, 1936). Confirmed sources of gem-quality green microcline closer to the Indus region and Harappa include those found in the pegmatites of Pakistan’s Northern Areas (Kazmi 1995b: 289). Perhaps the most likely source, however, lies in northern Gujarat. There, green microcline occurs in granite pegmatites southeast of Palanpur near the village of Derol (Foote 1898: 22) and amazonite pebbles originating from those rocks can be found in the bed of the adjacent Sabarmati River (ibid.: 29). On a loess terrace not far from this location, geologists R.B. Foote reported a prehistoric site where he recovered chert tools in association with amazonite fragments (Foote 1916: 142-143). Around 125 km southwest of this source area lays the Harappan site of Nagwada. Excavators there found chert drills and the abundant remains of amazonite beads in “different stages of manufacture” (Hegde et al. 1988: 58).

“Ochre” minerals

Several dozen examples of “ochre” minerals have been excavated at Harappa. The most common one is *hematite* – iron oxide (Figure 4.4 J). Appendix 4.2 K is a representative XRD scan of this mineral. A related hydrated iron oxide – *goethite* has also been positively identified (Appendix 4.2 L). Ochres such as these have a long history of

use as mineral pigments in South Asia (O.P. Agrawal 1999). Harappans certainly employed them when decorating ceramics (Dales and Kenoyer 1986a: 64) if not for other purposes.

Ochre minerals have been recovered from every mound at Harappa and from every one its occupational phases. Geologic occurrences exist across the Greater Indus region. Large and varied deposits of ochre are found in Jammu (Indian Bureau of Mines 2001: 27-29), the northern Punjab (Bender 1995b: 269), Balochistan (Ahmad 1975: 129), Sindh (Ahmad 1993: 18), western Rajasthan (Geological Survey of India 2001b: 88) and Gujarat (Merh 1995: 173). Residents of Harappa, however, would only have needed to travel 120 to 150 km north to find ample supplies. Red, yellow and green colored oxides of iron are found at numerous locations in the Kirana Hills and are mined today for use in the local paint industry (Butt et al. 1993: 8; Shah 1973: 10-11).

Lead minerals

Over half of the 35 lead artifacts found at Harappa are in the form of raw, unadulterated lead ore. Ore fragments (Figure 4.4 K) composed of galena (lead sulfide), galena with stibnite (antimony sulfide), cerussite (lead carbonate) with anglesite (lead sulfate) and massicot (lead oxide) have been identified using XRD (Appendix 4.2 M, N, & O). A variety of lead objects, residues and slags make up the rest of this sub-assemblage. A small lead rod was found to be partially composed of *wulfenite* (lead molybdate) and graphite (for details on this artifact including its XRD scan see Figure 12.21). With the exception of a single galena fragment from Ravi Phase levels on Mound AB, all of the lead artifacts excavated from secure contexts date to periods 3B or 3C. In Chapter 12, I discuss potential lead sources and investigate the probable geologic provenience of these artifacts.

Serpentine

The term s*erpentine* refers to a group of hydrous magnesium silicate minerals (lizardite, antigorite and chrysotile) that form due to hydrothermal alteration of ultramafic rocks such as peridotites (Deer et al. 1992: 344-352). These minerals have highly variable macroscopic characteristics. They may be opaque or translucent, come in colors ranging from white to green to black and can have either a uniform appearance or one with a mottled or winding (hence the name) pseudomorphic texture (ibid.). For many years, most green-colored translucent varieties of stone encountered at Harappa were believed to be serpentine. However, when all stones classified as such were examined in early 2003 using specific gravity (SG) testing, it was discovered that most were too dense to be serpentine and so they were reclassified as vesuvianite-grossular (serpentines have a SG of approximately 2.6 while vesuvianite-grossular ranges from ≈ 3.0 to 3.5). Only around thirty finished objects or fragments of stone from Harappa are now thought to be serpentine. A selection of these may be seen in Figure 4.4 L. Several of the fragments were examined using XRD and found to be composed of the variety of serpentine known as *lizardite* (see Appendix 4.2 P for a representative scan). Also using XRD, Vidale and Bianchetti (1997) had previously identified a lizardite bead at Mohenjo-daro.

Serpentine artifacts have been found on every mound at Harappa and from secure stratagraphic contexts representing periods 3A, 3B and 3C. Stone of this variety occurs at many locations around the Greater Indus region, especially in the ultramafic ophiolite sequences found along its northern and western margins (Asrarullah et al. 1979; Kazmi 1995b: 286). Bead and amulets composed of serpentine varieties that closely resemble

those found at Harappa are made today at the shrine of Shah Biwal Noorani in the southern Las Bela district of southern Balochistan (*personal observation*). The craftsmen working there confirmed that those varieties come from occurrences in the nearby ultramafic rocks of the Las Bela ophiolite. Identical looking serpentine minerals are found closer to Harappa itself in ophiolite sequences located in the Zhob district of Balochistan, North Waziristan, the Dargai area of the NWFP and the Gilgit-Skardu region of the Pakistan's Northern Areas (Awan 1987; Kazmi 1995b: 286; *personal observations*). Serpentine occurrences in central Rajasthan (Sen Gupta 1937) should also be considered as potential sources.

Miscellaneous rock and mineral varieties

Rock and mineral types for which ten or fewer examples have been recovered at Harappa are termed *miscellaneous* varieties (Figure 4.7). Although collectively these artifacts make up a mere 0.12% of the assemblage, they are as important as any of the more abundant materials in it because of the information they provide on the scope and diversity of Harappa's rock and mineral acquisition networks. The miscellaneous varieties are presented below in alphabetical order.

Almandine garnet

Almandine (iron aluminum silicate) is a dense (SG ≈ 4.3), dark red variety of garnet that occurs in thermally metamorphosed pelitic rocks (Deer et al. 1992: 31-46). A single battered fragment of an almandine garnet crystal (Figure 4.7 A) was found in Period 1 levels on the northern side of Mound AB. Another example came from disturbed sub-surface levels on Mound E. Using specific gravity testing, these artifacts were easily distinguished from similar looking but less dense (SG ≈ 3.6) pyrope garnet.

Figure 4.6: Sang-i-Miriam (fossiliferous limestone) **A**. Inlay, Lahore Fort, Pakistan **B**. Truncated conical amulet and worked block, Harappa **C**. Sang-i-Miriam at Habur, Jaisalmer District, Rajasthan **D.** Sang-i-Miriam at Khadir Island, Kutch, Gujarat



Figure 4.7: Miscellaneous rock and mineral varieties at Harappa



The garnets from Harappa might have come from any of several locations. Almandine is but one of the many varieties mined in garnet-rich Rajasthan today (Kanranth 2000: 200; Sethi 1966: 34-36). To the north of Harappa, gem quality almandine garnet is found in the Neelum Valley of Kashmir (Jan et al. 1995) and in various parts of the NWFP and Northern Areas of Pakistan (Kazmi 1995b: 289).

Almandine garnet is a hard stone (Mohs 7.25 to 7.5). Drilling this stone would have been impossible or at least very difficult with the tools Harappans possessed (although small beads could be made by "pecking" or chipping a hole through them). The Ravi Phase fragment could definitely not have been perforated using the chert and jasper (Mohs ≈ 7) tools available at that time. Even "ernestite" drills may have been largely ineffective. Blanche Barthélémy de Saizieu suggested (2003: 29) that hardness was the reason why garnet was infrequently used to make beads at the Neolithic site of Mehrgarh, in Balochistan. This may also account for why so little of this material is found at Harappa.

Calcite

Artifacts made of *calcite* (calcium carbonate) are rare at Harappa. The few calcite crystals (easily distinguished from naturally occurring pedogenic calcium carbonate nodules) that have been identified (Appendix 4.2 Q) could have come from any of the geologic formations surrounding the Upper Indus Basin. In 1990 a small, complete stone ring (Figure 4.7 B) was found by one of the local workmen at Harappa while walking across the site. It appears to be composed of *travertine*, or onyx marble (a form of calcite) and looks remarkably like the ornamental stone that is quarried on a large today in the Chagai Hills of Balochistan (Ahmad 1975: 124-128).

Fluorite

A light aqua-green-colored stone fragment was found in Period 3C levels of Trench 11 on Mound E while a similar looking material within a matrix of milky white crystalline stone (Figure 4.7 C) was recovered in disturbed strata nearby. The XRD results (Appendix 4.2 R) indicated that both were examples of *fluorite* (calcium fluoride) – a mineral with a history of use both as a flux for lowering the melting point of metals (its name derives from the Latin word *fluo* – "to flow") and as an ornamental stone (Deer et a. 1992: 673; Rapp 2002: 114). A broken aqua green colored bead found on the site's surface by one of the workmen had a specific gravity of 3.1 – exactly that of fluorite.

Fluorite is an extremely variable mineral both in terms of its appearance and the types of geologic environments that it forms in (Deer et a. 1992: 672-675). The artifacts from Harappa might have come from any number of regions except, importantly, some of those closest to it. No occurrences have been reported from the Salt Range, Sulaiman Range or Kirana Hills regions. Fluorite can be found in areas farther north of Harappa such as Dir and Hazara in the NWFP (Ahmad 1969: 81, Kazmi 1995b: 289), Ladakh (Waza et al. 1977) and Himachal Pradesh (Rawat 1983). To the west-southwest of Harappa in Balochistan, there are "trivial showings" in the northern Zhob District (Kazmi and Jan 1997: 468) while a rich cluster of occurrences is found in the northern Koh-i-Maran Range in the Kalat District (Mohsin and Sarwar 1980). Far to the south, the Amba Dongar fluorite deposit of eastern Gujarat is the largest in the Subcontinent (Balasubramaniam and Vekaria 1980). Finally, occurrences of this mineral are reported in various districts along the length of the Aravalli Range of Rajasthan (Geological Survey of India 2001b: 61-63).

Fossils

Several fossils have been found at Harappa including two large disc-shaped foraminiferans known as *nummulites* (Figure 4.7 D). The nummulite on the right hand side of the figure was found in the Period 3C Harappan dump debris that associated with the cemetery area. The one on the left was found in Period 4 levels on Mound AB. Fossils of this type can be found in Eocene formations of both the Sulaiman and Salt Ranges (Ashrafuddin and Farooqui 2002; *personal observations*).

Mica

Small sheets of mica (Figure 4.7 E) have been found in Period 3C levels and surface deposits on Mound E, Period 3C levels beneath the Mughal Sarai south of Mound E and in the Period 3C dump debris associated with the cemetery area. These were possibly related to gold-smithing or may have been used for medicinal purposes (Kenoyer 2006 *personal communication*). X-ray diffraction analysis indicates (Appendix 4.2 S) that these artifacts are of the mica variety *muscovite* (potassium aluminum silicate hydroxide fluoride). This mineral occurs in a wide range of metamorphic environments but is most common in granite pegmatites (Deer et al 1992: 292-293). Muscovite bearing pegmatites are found west and north of Harappa in Himachal Pradesh (Director – Punjab, Haryana and Himachal Pradesh Circle – Geological Survey of India 1971: 32), Kashmir (Ahmad 1981: 23) and the Peshawar and Hazara Divisions of the NWFP (Bender 1995b: 269). Of the many mica deposits found throughout Rajasthan (Geological Survey of India 2001b: 86-87), those in the northern Aravallis (Geological Survey of India 1989b: 32) would have been most accessible to Harappan peoples living on the plains of the upper Indus Basin.

Prehnite

Fragments of *prehnite* – a pale green mineral with a vitreous luster (Figure 4.7 F), have been recovered from Period 3C levels on Mound ET and directly identified using XRD (Appendix 4.2 T). Prehnite (calcium aluminum silicate hydroxide) most commonly forms either as a secondary hydrothermal mineral within cavities in basaltic rocks or as a primary mineral in contact metamorphosed impure limestones (Deer et al. 1991: 386). Those occurrences found in the Deccan Traps are examples of the former mode of formation (Wise and Moller 1990). In the latter instance, it may be found in association with vesuvianite-grossular − as it is in the ophiolite sequence near Muslimbaugh (formerly Hindubaugh) in the Zhob District, Balochistan (Bilgrami and Howie 1960). Prehnite has also been reported in or near other South Asian ophiolite sequences including those of Las Bela (Vredenburg 1904) and Waziristan (Badshah et al. 1997).

Sulfur

A small bright yellow stone fragment (Figure 4.7 G) recovered from a disturbed context on Mound ET was identified using XRD as pure *sulfur* (Appendix 4.2 U). The nearest occurrences of this mineral to Harappa, although very minor in size, would have been in the Salt Range, beginning 225 km north of the site (*personal observations*). Substantially larger sulfur deposits are found in Balochistan at Sanni in the Kalat District and Koh-i-Sultan in the Chagai Hills (Ahmad 1963).

Tourmaline

A fragment of green *tourmaline* – identifiable by its hexagonal structure, vertically striated exterior and glassy fracture (Figure 4.7 H) – was found in disturbed strata within

Trench 53, located between mounds AB and E. Minerals in the tourmaline group typically occur in granite pegmatites and can be found in colors ranging from opaque black to blue, green, red or clear (Deer et al. 1992: 130-137). Although tourmaline occurs widely across Rajasthan (Rajasthan Mineral Bulletin 1997a: 14), green varieties have not been reported. Gem-quality tourmalines of that color can be found at several localities in Pakistan's Northern Areas, as well as the Neelum Valley and Padar area of Kashmir (Jan et al. 1995; Kazmi and Jan 1997: 476; Mehta 1957: 62; Wadia 1975: 459).

Turquoise

Turquoise artifacts are found at Harappa in the form of beads and unworked fragments. One of the beads was recovered within a coffin burial dated to Period 3B and two fragments came from Period 3C levels. The remaining half dozen artifacts are from disturbed strata that were very likely derived from Period 3C or later levels. Despite being few in number, turquoise artifacts have been found on each major mound at the site.

Turquoise (hydrated copper aluminum phosphate) typically forms in arid environments as water peculates down through aluminum-rich rocks in the presence of copper (King 2002: 113). The color of this mineral can range from sky blue to apple green and it often patterned with patches or web-like seams of darker materials. There are several rocks and minerals, such as *azurite*, *lazulite*, *variscite*, *chrysocolla* and copper-stained chalcedony, which may resemble turquoise to the extent that they are mistaken for it or intentionally used as simulants for lapidary purposes (King 2002: 112; Pogue 1915: 131-133). Using XRD, two fragments from Harappa (Figure 4.7 I) were directly identified as true (mineralogically genuine) turquoise (see Appendix 4.2 V for a representative scan).

The existence of true turquoise deposits in South Asia has long been doubted (Bauer 1904: 397; Laufer 1913: 1-5). Occurrences reported in west-central Rajasthan near Ajmer and Ramgarh are now thought to "blue copper ore" or *azurite* – a hydrated copper carbonate (Iyer 1961: 72-73). More recently Jean-François Jarrige and Usman Hassan (1989: 160) reported the existence of old turquoise mining pits near Dalbandin in the Chagai Hills of western Balochistan. A sample of a blue-green turquoise-like material personally collected from that location by Jarrige was provided for this study and analyzed using XRD. The results of that scan (Appendix 4.2 W) indicate that the material is *not* turquoise but, rather, a stone composed mainly of quartz with a secondary phase(s) that suggests copper staining. The quartz content of this sample was further confirmed by placing a piece of it in hydrochloric acid. Turquoise will dissolve in acid (Pough 1989: 209) and the silica-rich Chagai sample did not. Chrysocolla (a hydrated copper silicate with a bright blue-green color) can become impregnated with silica and "may be confused with turquoise" (Poque 1915: 132). Jarrige's sample is, therefore, probably best characterized as "agatized" chrysocolla. E.W. Vredenburg encountered "turquoise blue" chrysocolla of this kind at multiple locations during his geologic survey of the western Balochistan region (Vredenburg 1901: 291-293). The Chagai Hills are certainly the type of geologic environment where turquoise *could* form and there are other mentions of the stone's occurrence there (e.g., Kazmi 1995b: 289). However, no conclusive studies have yet been published and so it is not considered as a potential source area at this time.

Turquoise then is the only rock and mineral variety in Harappa's assemblage other than lapis lazuli that, apparently, cannot be found in South Asia proper (considered here to

be the area encompassed by modern India and Pakistan). This makes it an excellent indicator of the extent of long-distance trade networks external to the Greater Indus region. It is unlikely that Harappan turquoise trade networks extended all the way to deposits in Egypt (Hussein et al. 1995) or central China (Qi et al. 1998; Qian and Xu 1993) simply because there were much closer sources of that material. Perhaps the best known of these are the famous mines at Nishapur and Damghan in northeastern Iran (Khorassani and Abedini 1976; Manutchehr-Danai 1977). Maurizio Tosi (1974b), however, suggests that those sources may not have been exploited during the third millennium BC and instead points to deposits in Uzbekistan's Kyzyl Kum desert (Klyavin 1974) that were clearly being worked at that time as the likely source of the many turquoise artifacts found at Helmand Tradition sites of Shahr-i-Sokhta and Mundigak (Bulgarelli 1981; Jarrige and Tosi 1981). Material from the Kyzyl Kum deposits and perhaps other Central Asian sources like the one in the Akturpak region near the Ferghana Valley (Turesebekov and Meshchaninov 1983), could have entered Indus trade networks indirectly via Harappan interaction with the turquoise-using Helmand Tradition cultures. On the other hand, turquoise artifacts are found at the Harappan site of Shortughaï in northern Afghanistan (Francfort 1989: 145). At least some material from Central Asian sources may have entered Indus acquisition networks via that region. Lastly, the turquoise deposits of Tibet (Pogue 1915: 42) must be considered as potential sources. Occurrences in the western part of that region are the closest ones to Harappa and there is clear evidence that connections existed between cultures of the northern Subcontinent and those of the Tibetan Plateau and beyond during the third millennium BC (Fairservis 1975: 312-218; Stacul 1992, 1994; Xu 1991).

Various unidentified materials

There are a few artifacts in Harappa's rock and mineral assemblage that, for various reasons, have not yet been positively identified. The first two discussed below are examples of complete, one-of-a-kind objects that cannot be subjected to destructive analyses.

Nephrite jade?

A semi-translucent, spinach-green colored truncated conical amulet with a high-polish (Figure 4.7 J) was recovered in a cemetery burial pit dated to Period 3B. This artifact (H88/182-14) has a specific gravity of 3.0, which is precisely that of *nephrite*. Nephrite is a metamorphic rock (a sodium aluminum iron silicate in the actinolite series) that, in addition to the metamorphic mineral *jadeite* (calcium magnesium iron silicate hydroxide), is, by widely accepted convention, one of the two mineralogically genuine varieties of *jade* (Twilley 1992). Although neither variety is, in a geologic sense, uncommon (ibid.), gem-quality occurrences of this stone are known from only a very few locations in Asia. None of these are in South Asia and it is perhaps for this reason that jade was not widely used there until the Mughal Period (ca. 16th century AD) (Skelton 1995). Reports of "jade" beads from early excavations at Harappa (Beck 1940: 402) and Mohenjo-daro (Mackay 1931c: 519, Mackay 1938: 498, 527), have led some scholars to suggest (Allchin and Allchin 1982: 186; Mackay 1948: 83) that long-distance exchange networks existed between the Indus region and distant parts of Asia where gem-quality nephrite (western China) or jadeite (Myanmar) can be found. I later (Chapter 9) argue that, given their reported macroscopic and physical properties, it is very likely the beads from those earlier excavations were misidentified and are actually made of vesuvianite-grossular

garnet rather than either form of jade. However, with regard to the spinach-green-colored truncated conical amulet, I believe that it might actually be genuine nephrite jade and may have been obtained from a source within the Greater Indus region.

The stone from which the Harappan amulet was fashioned, although having the exact density of nephrite, is generally too light in weight to be vesuvianite-grossular garnet. Although a few fragments of vesuvianite from Harappa with specific gravities of around 3.0 have been recorded, they are highly weathered examples that have numerous fractures filled with chlorite. The material composing the amulet in question is unweathered and flawless. It also possesses a much deeper green color than typical for vesuvianite-grossular and has a high, very "jade-like" polish, especially around its grooved "neck." In addition, the amulet is too dense to be one of the other types of green-colored stone found at Harappa, such as serpentine (which it was originally recorded as – see Kenoyer 1998: 208) or quartz. A conclusive identification as nephrite, however, will have to wait until such time as its geochemical properties can be directly tested (perhaps using non-destructive X-ray fluorescence analysis).

If the amulet is eventually shown to be nephrite jade, then it *could* mean that Indus Civilization peoples had some form of long-distance access north beyond the Karakoram Range to the well-known nephrite source along the Karakash River near Khotan (Hetain) in the western Chinese province of Xinjiang (Tosi 1977). The existence of the Indus Civilization outpost of Shortughaï in northern Afghanistan (Francfort 1984b) amply demonstrates that Harappans had the ability to travel to regions beyond the high mountain ranges of northwestern South Asia if they so desired. However, access to Khotan nephrite

(if that is what the amulet is composed of) was probably indirect and carried out through trade with the non-Harappa cultures inhabiting the mountainous north of Pakistan and India. Those groups had clear cultural affinities with Inner and East Asia (Fairservis 1975: 312-318; Stacul 1994; Xu 1991) and the light-green colored jade beads and pendants recovered at the sites of Ghalegay and Loebanr in the Swat Valley of northern Pakistan (Stacul 1987: 75) quite possibly came from sources in nearby western China. On the other hand, it is also possible that the jade from which those particular ornaments were fashioned was derived from pods of jadeite identified in the Ladakh region of northern India (Singh and Gupta 1987). The Harappan amulet, however, is much too light to be the jadeite variety of jade, which has a specific gravity of 3.24 to 3.43 (Deer et al. 1992: 192).

Even if the existence of nephrite jade at Harappa or any other Indus Civilization site is eventually confirmed, it still cannot be taken as conclusive evidence of long-distance trade with Khotan region of western China. The possibility exists that the material may have been acquired from sources within the Greater Indus region. Geologist B.C.M. Butler of Oxford University collected two small cobbles from the Teri Toi river bed in the Kohat District, NWFP, which, using a combination of petrography and XRD, he positively identified as being composed of nephrite jade (Butler 1962). Butler believed (but was not able to confirm) that the cobbles had to have eroded from nearby conglomerate beds of the Middle to Upper Siwaliks (ibid.: 389-390) as there were no *in situ* metamorphic formations in the area from which they could have derived. If he was correct, then it is conceivable that nephrite, although perhaps rare, might be found at various other points along the western and northern margins of the Indus Basin where Siwalik conglomerates containing

metamorphic clasts also occur (Brozović and Burbank 2000; Cheema et al. 1977: 89-98). Most significantly for this study, Butler described (1962: 387) the larger of the nephrite cobbles from Kohat as having a translucent "spinach-green" appearance – exactly like that of the Harappan amulet. The description of the smaller cobble – “pale greenish-white” (ibid.: 386), is reminiscent of the jade ornaments from the sites in Swat.

Volcanic glass?

An elliptical green-colored bead with a vitreous, banded appearance (Figure 4.7 K) was recovered in a Kot Dijian Phase (Period 2) hearth on Mound AB, Trench 39. This unusual find is thought perhaps to be composed of some form of volcanic glass (Meadow et al. 2001: 10). Previously, a dense (SG 3.058), brownish bead at Mohenjo-daro was identified as *tachylite* – a variety of basaltic volcanic glass (Mackay 1931c: 546). The bead from Harappa, however, has a specific gravity (2.55) more in line with the average density for *obsidian* (SG 2.6). Obsidian is a volcanic glass that, because it decomposes (devitrifies) relatively quickly as it hydrates, is usually found in geologically recent formations (Pough 1988: 14-15). In the collections of the Geological Survey of Pakistan–Quetta, there is an example of black obsidian with a slight greenish cast that was collected from the Pleistocene era volcanics of the Chagai Hills, western Balochistan (*personal observation*). Older occurrences of *undevitrified* volcanic glasses of various kinds have been reported, however, such as those in Deccan trap rock near Kagvadar and Loingdi-Bhaguda, Amreli District, southern Saurashtra (Misra 1999: 327). Closer to Harappa, beds of volcanic glass are described in the Permian era Warcha Sandstone at Nilwahan Gorge in the central Salt Range (Butt and Mateen 1996). Significantly, the series of Kot Dijian sites that have

recently been identified in those mountains (Dar 2002) date to the same period from which this unusual bead was recovered at Harappa.

Green and blue "earth"?

Among the as-yet-unidentified/uncharacterized geologic materials recovered during excavations by the HARP are both bluish and green-colored sediments that *may* be remnants of mineral pigments. *Green earth* (or *terra verde*) is a broad term used for a type of green-colored pigment sometimes made from oxides of iron (Edholm and Wilder 1998), but usually made of either *glauconite* or *celadonite* – hydrated aluminosilicates of magnesium, iron and potassium (Genestar and Pons 2005: 273-274). The latter two materials, although separate mineral species (Buckley et al. 1978), are often difficult to differentiate, even using sophisticated analytical techniques (Duplay and Bautier 1990). Nodules of glauconite, which is form under shallow marine sedimentary conditions, can be found in the Chichali-Kalabaugh area of Salt Range, Pakistan (Ahmad et al. 1966) and at many locations across northwest India (see Srivastava 1986 for more than a dozen separate articles discussing these sources). Celadonite forms from the weathering and low-grade metamorphism of volcanic rocks and, thus, many of the green earth occurrences of this type in India are associated with rock of the Deccan Traps (Bhusari 1964; Ghate 1971). Sir Edwin Pascoe suggested (1931: 685) that examples of green earth identified at Mohenjo-daro could have come from that region or, in his opinion more likely, the volcanic formations found intermittently across in Balochistan.

Green earths have a long history of use as pigments in South Asia (O.P. Agrawal 1999). Although the more recently discovered "pigments" from Harappa have not yet been

positively identified, the archaeological chemist Khan Bahadur Mohammad Sana Ullah did analyze samples of both "blue and green earth" found during earlier excavations at the site. The compositions that were reported for those samples (in Vats 1940: 468-469) are consistent with glauconite/celadonite. Green earths are "often diluted with white silicates or mixed with colored compounds to obtain new colors" (Casellato et al. 2000: 230) and so that might account for those examples from Harappa with a bluish cast. The "blue earth" sample analyzed by Sana Ullah (Vats 1940: 468) was reported to contain a small amount (0.88%) of *titanium dioxide*, which is a common white pigment. However, titanium dioxide is not known to have been synthesized prior to the modern era and its presence in pigments or inks has been used as evidence against claims for the antiquity of certain objects, such as in the case of the Vinland Map (Henchman 2004; Towe 2004). The detection of this substance in the Harappan sample, although possibly due to the presence of natural anatase (TiO_2), is very intriguing.

Material varieties at Harappa known only from previous excavations

Several materials were found during earlier excavations at Harappa that have not been encountered again in the nearly two decades of work there by the HARP. For this reason, they were not considered when calculating the proportions of the different varieties making up the site's rock and mineral assemblage. Relatively few examples of these materials are recorded in Vats' 1940 site report and so, more than likely, they would have fallen into the miscellaneous category. It is, nevertheless, important to discuss them here in order to fully illustrate the range of rocks and minerals in use at Harappa and to thoroughly assess the extent and possible directions of acquisition routes.

Silver

No artifacts made entirely of silver have, as of yet, been recovered during HARP operations, although gold sheeting wrapped around what may be a silver wire has been found as well as a small lump in which gold and silver have been cold hammered together. A small number of artifacts from mounds AB and F made entirely of silver (a vase, a broach, a bangle, two bosses and various beads) are recorded in Vats' 1940 excavation report. The apparent scarceness of this precious metal at Harappa, rather than being indicative of its limited of use there, may largely be due to factors relating to its preservation (or rather lack of) in the saline, moisture-laden soil of the site. Silver, in contrast to gold, is oxidizable and much more water-soluble (Guilbert and Park 1986: 744). Under certain burial conditions it is subject to "complete disintegration through severe internal corrosion and embrittlement" (Drayman-Weisser 1992: 192). Thus, many of the objects made of this material that escaped recycling four millennia ago at Harappa may have since degraded to the point that little or no trace has been left behind (especially small ornaments and tiny fragments). Still, we have been able to glean from the discovery of jewelry hoards and individual finds at numerous other settlements, both large and small, across the Greater Indus region that silver was an important and widely traded metal during the Harappan Period (for details on these see Ratnagar 2004: 197 or Lahiri 1992). In Chapter 12, I present the results of compositional and geologic provenience studies of silver artifacts from several of those other sites. Here, I make a few remarks regarding how Harappans may have acquired this metal and from where.

Silver in its native state is quite rare, much more so than native gold (Dana 1957: 404). For this reason, it is thought that the majority of this metal used throughout history was won by the *cupellation* (refinement through the oxidation of base metals) of *argentiferous* (silver-rich) lead ores (Rapp 2002: 147). A number of scholars have suggested that Harappan silver probably was derived in that way (Asthana 1993: 276; Biwas 1996: 329; Mackay 1931c: 524; Ratnagar 2004: 193; Sana Ullah in Mackay 1938: 599). A lead ore body may be considered viably argentiferous if it contains more than ten parts per million (10 ppm) silver (Craddock 1995: 211). Such deposits are found at multiple locations across northwestern South Asia (I discuss these, along with the other lead deposits of the Greater Indus region, in Chapter 12). In addition, small amounts of lead were detected in analyses of silver artifacts from Mohenjo-daro (Hamid, Sana Ullah in Mackay 1938: 478, 599) and Lothal (Lal 1985: 656), which *might* indicate that the metal used to make those objects was derived from a lead ore rather than native silver.

It is worth pointing out that ores such as chalcopyrite and chalcocite can also be argentiferous (Craddock 1995: 232; Dana 1941: 402; Gregg 1934) and, therefore, the possibility exists that at least some of the silver found at Indus Civilization sites may have been a byproduct of copper production. In fact, in the analyses of silver artifacts from Mohenjo-daro and Lothal cited above, copper was detected in much greater amounts (from 2.67% up to 7.87%) than was lead (from 0.42% to 1.64%). Copper (and for that matter lead) could have been deliberately added during the manufacture of those objects (Bhardwaj 1989: 327), but this is by no means certain. What is certain is that Harappans were heavy consumers of copper and that silver is currently being recovered from

argentiferous copper deposits in two regions that may have been exploited in the late-prehistoric era – the Khetri copper belt of northern Rajasthan (Rao et al. 1997) and the Saindak copper prospect of western Balochistan (Mining Magazine 2001; Wolf 1974).

Arsenical minerals: Löllingite and Orpiment

Two arsenical minerals were recovered from Harappan Period levels on Mound F during excavations in the 1920s. A "black lump" found in Vats' Trench I was identified by Sana Ullah (in Vats 1940: 90) as *löllingite* (iron arsenide). Specimens of this material were also recovered at Mohenjo-daro (Pascoe 1931: 684-685, 690). Löllingite is a relatively uncommon mineral that can form both in sulphide deposits and pegmatites. Occurrences of the latter type are reported in association with gem-quality tourmalines in the Stak Valley of Pakistan's Northern Areas (Laurs et al. 1998) and in the gold-bearing Dhawar schists of the Gulbarga District, Karnataka (Mahadevan and Krishna Murthy 1945). In the Banswara District of southeast Rajasthan, native gold occurs with löllingite and arsenopyrite at Bhukia (Golani et al. 1999).

In Vats' Trench V, a small lump of *orpiment*, or arsenic sulphide, was recovered (Vats 1940: 468). This substance may have been used to alloy copper (although Kenoyer and Miller 1999 consider this unlikely), as a yellow pigment (O.P. Agrawal 1999: 191) or even for medicinal purposes (Treleaven et al. 1993; Watt 1885: 321). Orpiment, like löllingite, is not a common mineral. In Pakistan, it is mined in Chitral and small amounts are found at a few other locations in the north of the country (Ahmad 1969: 4-5; Shams 1995b: 255). "Minor occurrences" and "scattered fragments" are reported in the Zanskar and Kumaon regions of the Himalayas (Chatterjee 1963a: 12; Krishnaswamy 1979: 55).

Fuller's Earth

During the 1924-25 excavation season at Harappa, a wide (≈ 3.5 m) but shallow (≈ 55 cm) depression was encountered among a group of houses in the central part of Mound AB (Vats 1940: 154). Lining the depression was a "filmy coating of bluish green earth with a soft, soapy feel," which was later identified by Sana Ullah (ibid.) as *Fuller's Earth* or, as it is known in this part of South Asia, *Multani Mitti* (Multan Earth). Fuller's Earth is a type of highly absorbent calcium montmorillonite clay that has been used throughout history as a substance for cleaning textiles (Robertson 1986). The designation "Fuller" refers not to a person but to an occupation – one who scours, or *fulls*, cloth to make it clean (Aronson 1996). Evidence that suggests some sort of washing activity may have taken place at the location at Harappa where this soapy material was found. The depression, or "reservoir" as it is noted on the trench plan (Vats 1940: Plate XXXII), which the Fuller's Earth was lining is situated in an area, perhaps a courtyard, where water was clearly being used and controlled – there are brick-on-edge platforms nearby, a water chute and several drains including a long one that would have carried waste water away from the area.

Sana Ullah inferred "that this earth was imported" (in Vats 1940: 154) and he was certainly correct as there would have been no local sources for this variety of clay. The most extensive deposits of Fuller's Earth in northwestern South Asia occur in Sindh, especially in the Lakhi Range and the Rohri Hills area between Sukkur and Kot Diji (Ahmad 1969: 67; Shah 1977: 115). Numerous occurrences may also be found throughout the west and northwestern portions of Rajasthan (Department of Mines and Geology 1989: 81-82; Pareek 1984: 71). The deposits nearest to Harappa, however, are found just over

200 km directly west of the site in the Rakhi Nala and Taunsa areas of the Sulaiman Range piedmont (Hassan et al. 1995: 31-32; Shah 1977: 115; Yusaf et al. 1989).

Spatial and temporal aspects of Harappa's rock and mineral assemblage

Now that Harappa's rock and mineral assemblage has been presented in all of its diversity, it is possible to take a step back and examine it on a broad-scale, as a single entity, composed of many different and potentially variable "elements." These "elements" are the major, minor and miscellaneous rock and mineral varieties that have been defined and described in this chapter. In this section, I am mainly concerned with which of them are present or absent in a particular chronological phase and/or on one of the major habitation areas at the site. Much more detailed examinations of select varieties take place in the eight chapters that follow this one. The purpose here is to determine if the suite of rocks and minerals acquired and used by Harappans, *as a whole*, varied from period to period and from mound to mound. If it did, then how does that inform the three lines of inquiry that were outlined in Chapter 1? Before addressing those questions, however, it is necessary to consider the following issue: To what degree is any evident variation in the composition of the rock and mineral assemblage a reflection of the actual behaviors of Harappans living in different periods and/or parts of the site, as opposed to being due to other factors, such as the physical constraints of the site and the research strategies of the excavators? In order to evaluate this, it had to be taken into account how the assemblage, as a set of deliberately recovered archaeological remains, was distributed across space and time at Harappa. The first task was to determine the spatial and temporal contexts of the artifacts making up Harappa's rock and mineral assemblage.

Contextualizing the rock and mineral assemblage

In order to determine the spatial and temporal contexts of the artifacts making up Harappa's rock and mineral assemblage, a list of every excavation/survey unit (known as a "lot") that contained one or more stone or metal objects was first compiled using the tabulation database. Excavation field books and stratigraphic section drawings were then consulted. Those lots associated with stratigraphic contexts that were not secure (surface, sub-surface rubble, the fill inside of brick-robber trenches, root holes, animal burrows, etc.) were flagged. The remaining ones were synchronized with unpublished lists of lot chronological associations already worked out by Drs. Mark Kenoyer and Richard Meadow for certain phases and areas of the site. Using the field books and section drawings, Dr. Kenoyer and I went then through the entire list again, lot by lot, to confirm associations. The stratigraphy of Harappa is highly complex and contextual data in the tables below should be considered provisional until a final version is published by the HARP directors.

The spatial and temporal distribution of the rock and mineral assemblage

The physical locations where rock and mineral artifacts are found at Harappa reflect the behaviors of its prehistoric inhabitants as well as various other site formation processes (some cultural, some not) that have acted upon them. The way in which the assemblage that is available for study is spatially and temporally distributed, however, is a function of both the physical aspects of the site as well as the strategies of the researchers who recovered the artifacts. For various reasons, some time periods and areas at Harappa are better represented in the assemblage than others. It is vitally important to be mindful of this when comparing sub-assemblages from different parts of the site and from different phases.

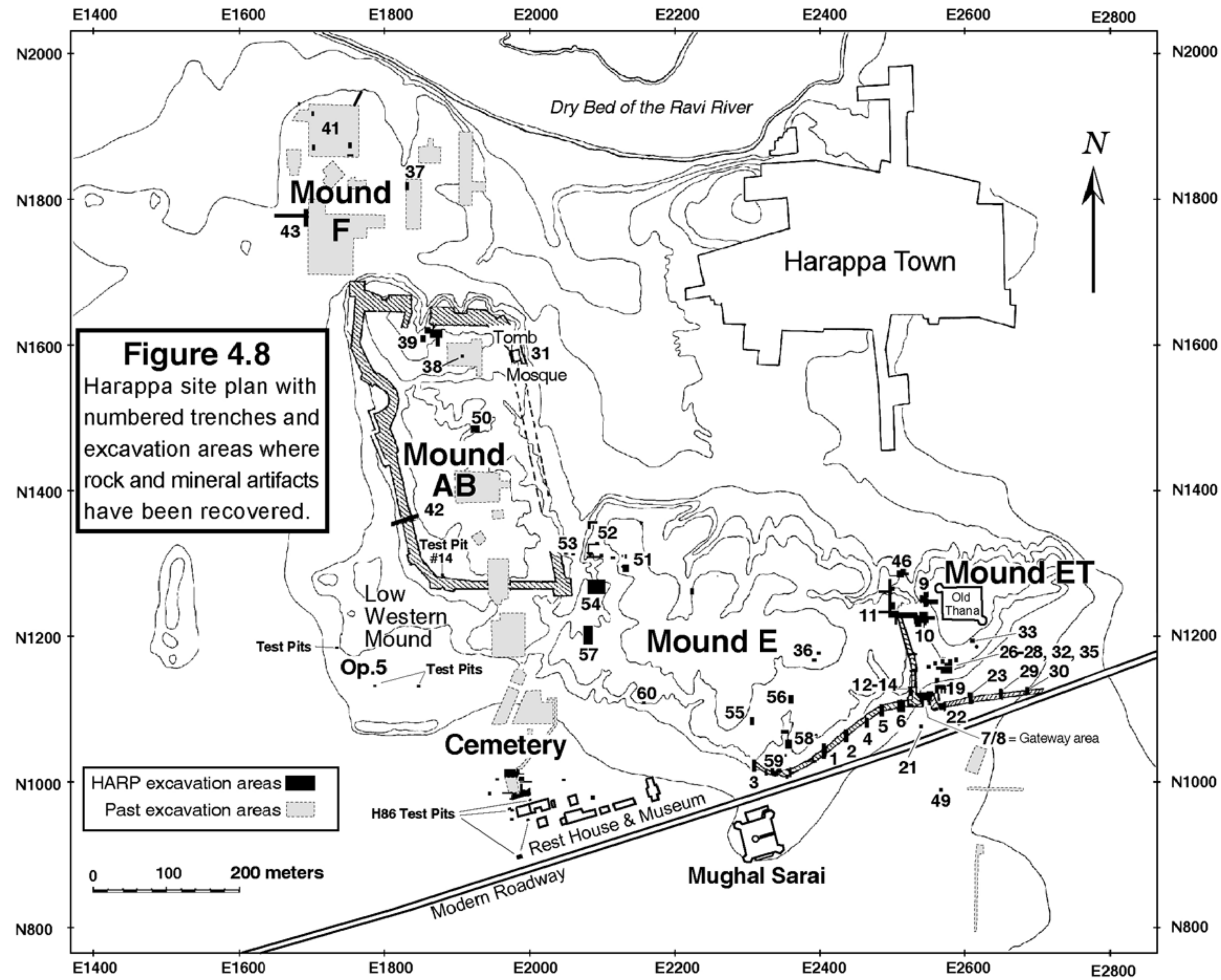


Figure 4.8
Harappa site plan with numbered trenches and excavation areas where rock and mineral artifacts have been recovered.

On the preceding page is the site plan of Harappa (Figure 4.8). Marked in black and labeled by trench, operation (Op.) or test pit (TP) number are the HARP excavation areas in which rock and mineral artifacts have been recovered. This basically includes all but a handful of the trenches (mostly small test pits) that have been placed at the site by the HARP. The areas of Harappa excavated by past researchers are marked with gray shapes. Figure 4.9 is a table showing how the rock and mineral assemblage recovered during HARP operations is distributed among the major areas of the site. Since the project commenced in 1986, much of the research emphasis has focused on those parts of Harappa that had not been examined during previous excavation projects – namely, mounds E and ET. Nearly every season has seen large-scale excavations conducted in those areas. Although test pits, small trenches and surveys were made in all parts of the site during the early years of the project, it was not until the mid-1990s that large-scale excavations began on Mound AB and not until the later-1990s that they started on Mound F. As a consequence, most of the rock and mineral artifacts recovered over the past two decades – fully two-thirds of the site's entire assemblage, comes from the conjoined area of mounds E and ET. Mounds AB and F together comprise roughly half of Harappa's main habitation area but are represented by only around one-quarter of the total assemblage.

Figure 4.9: Distribution of Harappa's rock and mineral artifact assemblage among the major areas of the site (based on all 56,350 artifacts)

location	*percentage*
Mound **AB**	19.54%
Mound **E**	40.14%
Mound **ET**	26.51%
Mound **F**	6.73%
Mughal Sarai	0.31%
Other* (cemetery, dumps, misc. finds, off-mound survey)	6.76%

Figure 4.10 is a table showing how Harappa's rock and mineral assemblage is distributed among site's the periods and sub-periods. Distribution was calculated in two different ways: 1) Of the approximately 56,000 artifacts making up the rock and mineral assemblage, exactly 32,365 are from chronologically secure contexts. The percentages in the second column of the figure were calculated based on the total number of stone artifacts from secure contexts that are found in each period. 2) Of the approximately 10,000 excavation or survey units (lots) that have been assigned to date, around 4000 contained at least one stone or metal artifact. About three-quarters (n = 3024) of those lots represent chronologically secure strata. The percentages in the third column of the figure were calculated based upon the number of individual lots containing stone within each period.

Figure 4.10: Distribution of the rock and mineral assemblage through each chronological phase and by excavation areas. Percentages based upon number of artifacts from secure contexts (total n = 32,365) and number of excavation lots containing stone artifacts (total n = 3024). Excavation areas list by Trench number or abbreviation (C = Cemetery, S = Sarai, TP = test pit)

	by artifact	*by lot*	*Trench / excavation area*
Period **1**	11.59%	5.39%	39
Period **2**	7.95%	9.33%	1, 2, 11, 39, 42, 52, 58
Period **3A**	6.10%	4.66%	1, 2, 10, 11, 21, 39, 42, 52, 54, 58, 59, C
Period **3B**	10.88%	19.84%	1, 9, 10, 11, 21, 22, 37, 39, 42, 49, 52, 54, 56, 57, 58, C, TP-14
Period **3C**	62.81%	59.95%	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 19, 21, 22, 23, 27, 28, 31, 32, 33, 35, 36, 37, 39, 41, 42, 43, 46, 50, 51, 52, 54, 55, 56, 58, 59, 60, C, S, TP-H86, TP-Op.5
Period **4**	0.17%	0.40%	38, 43
Period **5**	0.49%	0.43%	38

Both methods of calculation result in overall similar distribution patterns. It is at once evident that stone artifacts belonging to Period 3C dominate the dateable assemblage (comprising around 60% of the total). This is not at all surprising as most of the Harappa's surface area consists of strata belonging to that sub-period and therefore nearly every excavation trench placed at the site encountered those levels. Stone from earlier periods was recovered in only a limited number of trenches. The fourth column of Figure 4.10, which shows the numbered trenches and/or other excavation areas that are associated with each chronological phase, quite clearly illustrates phenomenon. The considerably smaller percentages for the others periods is due to either their comparatively limited exposure (periods prior to 3C) or lack of preservation (periods after 3C). It may seem counterintuitive that the Period 3A assemblage is smaller than the even more deeply buried periods 1 and 2. However, this is due to the fact that most (or all in the case of Period 1) of the stone artifacts representing the initial two chronological phases at Harappa come from the large-scale exposures of Trench 39, which was placed at a point on the northern edge of Mound AB where the overburden of later levels was minimal. Substantially fewer Period 3 artifacts were recovered in that particular large trench than would normally be expected when exposing an area of Early Harappan levels of that size. Although Period 3A levels were reached in many more trenches, the areas actually exposed in each were very small.

Figure 4.11 details the temporal and spatial distribution of the rock and mineral assemblage among the main mounds at Harappa. Because one of the aims of this dissertation is to compare acquisition and use patterns between parts of the site that may have been controlled by different social/political groups, the roughly seven percent of the

assemblage that comes from cemetery and off-mound contexts, which cannot realistically be associated with one or another group, was excluded from the calculations for this particular table. With the focus on just the four main walled areas, the equities and, mostly, disparities in how the assemblage is distributed among them during the various periods become quite clear. Although there is evidence for a Ravi Phase occupation in the area of what is the northwest corner of Mound E, all of the stone representing Period 1 presently comes from Mound AB. Similarly, evidence for a Late Harappan Phase occupation exists over large parts of the site but the only stone from secure Period 5 levels comes from a small area on Mound AB. Period 3A has the most equitable distribution of rock and mineral artifacts between the two largest habitation areas at Harappa (54% for AB vs. 43% for E) but, aside from Period 4/5, the smallest sized sub-assemblage of any phase (refer back to Figure 4.10). The largest rock and mineral sub-assemblage dates to Period 3C, but nearly 80% of it comes from the conjoined area of mounds E-ET. Artifacts from those mounds comprise nearly 90% of the sub-assemblage for Period 3B.

Figure 4.11: Temporal and spatial distribution of Harappa's rock and mineral assemblage. Percentages calculated by the number of artifacts recovered from secure contexts in walled mounds only (cemetery/off-mound artifacts excluded).

	Period **1**	Period **2**	Period **3A**	Period **3B**	Period **3C**	Period **4**	Period **5**
Mound **AB**	100%	84.06%	54.30%	6.20%	5.24%	96.36%	100%
Mound **E**	not excavated	12.52%	43.02%	53.89%	39.02%	not excavated	not excavated
Mound **ET**	not present	3.42%	2.68%	35.54%	40.36%	not excavated	not excavated
Mound **F**	not present	not present	not present	4.36%	15.38%	3.64%	not excavated

It is worth acknowledging that sub-assemblages recovered from different phases and/or mounds at Harappa are not necessarily equally representative samples of the contexts to which they belong. In order to begin to get a truly accurate picture of how representative they may or may not be in relation to each other, it would be necessary to know the total volume of the strata comprising each period (both for the site and for each mound) and compare that to the volume of excavated strata for each period. Calculations of this type have not yet been completed due to the complexity of Harappa's stratigraphy. In spite of that, informed comparisons between sub-assemblages can still be made as long as proper consideration is given to differences among the contexts under examination. For example, nearly 12% of the 32,365 stone or metal artifacts from secure contexts were recovered in a single trench that reached Ravi Phase levels, while roughly 60% of them came from 40 excavation areas that exposed Period 3C contexts (refer back to Figure 4.10). Judging from the temporal distribution pattern alone it might appear that the sub-assemblage for Period 1 at Harappa is not as representative of the Ravi Phase as the one for Period 3C is of that phase. However, the size disparity between these two chronological sub-assemblages is mitigated somewhat when it is recognized that the Ravi Phase occupation (estimated is have been at most 10 ha in area – Kenoyer and Meadow 2000: 56) was much smaller than that of Harappa Phase 3C (estimated to have been 150+ ha – Meadow and Kenoyer 2001: 26). As sets of artifacts belonging to different periods and areas are compared in the following section and throughout this dissertation, every effort is made to similarly consider potential assemblage distribution biases in light of differences in the nature and extent of the temporal and spatial contexts under examination.

Spatial and temporal variations in the rock and mineral assemblage

Having shown how Harappa's rock and mineral assemblage is distributed across the site, potential spatial and/or temporal variation of the "elements" that make it up can be properly examined and evaluated. In Figure 4.12, the major, minor and miscellaneous rock and mineral varieties at Harappa are cross-listed with the contexts in which they occur. Those present in a particular context are identified in the columns using the one or two letter code that signifies the mound or other part of the site where they were recovered. On the bottom row on the figure the total number of varieties present at Harappa in each phase is noted in bold print while the totals from each mound are in parentheses. Also on this row, two of the "unidentified" materials are noted in the period and place they occur using the symbols "+" (for the Period 2 bead that may be obsidian) and "#" (for the Period 3B pendant that may be nephrite).

At first glance it would appear that, from Period 1 through Period 3C, there is an trend toward greater diversity in terms of the variety of the rocks and minerals used by Harappans. Fourteen varieties have been recovered in both the Ravi and Kot Diji phases (although not entirely the same ones) while at least 22 were in use by the final phase of Period 3. The steep drop (to 11) in the number present in Late Harappa (Period 4/5) levels could be taken as evidence of a dramatic reduction of acquisition networks during that period. It also appears that there were synchronic differences in the number of varieties to which residents living on different mounds at Harappa used or had access. Except for Period 2, in all chronological phases for which stone has been recovered in multiple areas of the site there are a greater number of varieties found on conjoined mounds E and ET.

Figure 4.12: Distribution of rock and mineral varieties by period and by mound or other* areas *(C = Cemetery, S = Sarai)

Variety ↓ / *Context* →	**1**	**2**	**3A**	**3B**	**3C**	**4/5**	**surface / disturbed**
1. Steatite	AB	AB, E, ET	AB, E, ET, C	AB, E, ET, F, C	AB, E, ET, F, C, S	AB, F	AB, E, ET, F, C, S
2. Chert	AB	AB, E, ET	AB, E, ET	AB, E, ET, F, C	AB, E, ET, F, C, S	AB	AB, E, ET, F, C, S
3. Agate-Jasper	AB	AB, E, ET	AB, E, ET, C	AB, E, ET, F, C	AB, E, ET, F, C, S	AB	AB, E, ET, F, C, S
4. Copper	AB	AB, E, ET	AB, E	AB, E, ET, F	AB, E, ET, F, C, S	AB	AB, E, ET, F, S
5. Siliclastic rocks	AB	AB, E	AB, E	AB, E, ET, F, C	AB, E, ET, F, C, S	AB	AB, E, ET, F, C, S
6. Vesuvianite-grossular	AB	x	x	E, ET	AB, E, ET, F, C, S	AB	AB, E, ET, F
7. Igneous-metamorphic	AB	AB, E	AB, E, C	AB, E, ET, F, C	AB, E, ET, F, C, S	AB	AB, E, ET, F, C, S
8. Gypsum	AB	AB	AB, E, ET	AB, E, ET, C	AB, E, ET, F, C, S	x	AB, E, ET, F, S
9. Limestone	x	AB	x	E, ET	AB, E, ET, F, C, S	x	AB, E, ET, F
10. Lapis lazuli	AB	AB, E	AB, E	E, ET, C	AB, E, ET, F, C	AB	AB, E, ET, F
11. Crystalline quartz	x	AB	AB, E	E, ET, F	AB, E, ET, F, C	x	AB, E, ET, F, S
12. Gold	AB	AB, E	AB, E	E, ET, C	E, ET, F, C	x	AB, E, ET, F, C
13. "Ernestite"	x	x	x	ET	E, ET, F, C	x	E, ET
14. Amazonite	AB	AB	x	F, C	AB, ET, F	AB	AB, ET
15. Ochre Minerals	AB	AB, E	E	E	E, ET, F	AB	AB, E, ET
16. Lead	AB	x	x	C	E, ET, F	x	E, ET, F
17. Serpentine	x	x	E	AB, E	E, ET, F, C	x	AB, E, ET
18. Almandine garnet	AB	x	x	x	x	x	E
19. Calcite	x	x	x	x	x	x	?
20. Fluorite	x	x	x	x	E	x	E, ?
21. Fossil foramina	x	x	x	x	C	AB	x
22. Mica	x	x	x	x	E, C, S	x	x
23. Prehnite	x	x	x	x	ET	x	x
24. Sulfur	x	x	x	x	x	x	ET
25. Tourmaline	x	x	x	x	x	x	(AB-E)
26. Turquoise	x	x	x	C	ET, F	x	AB, E
total varieties present + *obsidian*? # *nephrite*?	**14**	**14+** – AB(14+) E(9) ET(4)	**12** – AB(10) E(12) ET(4)	**19#** – AB(8) E(14) ET(13) F(8) C(#)	**22** – AB(12) E(18) ET(19) F(17) S(10)	**11**	**23** – AB(17) E(20) ET(18) F(13)

The patterns evident in Figure 4.12 cannot simply be taken at face value, however. When they are considered in relation to figures 4.9 through 4.11, it is clear that there is a direct correlation between the spatial and temporal distribution of the assemblage and its diversity in different periods and areas. Quite simply, those mounds and phases from which the largest sub-assemblages were recovered are also the ones that exhibit the greatest diversity of rock and mineral varieties. Those with the smallest-sized sub-assemblages are the least diverse. So although it might be tempting say that Harappans dwelling on mounds E-ET during Period 3C had access to and were utilizing a much wider range of rocks and minerals than their counterparts in other periods and areas of the site, I do not think that such a statement is tenable. Much of the apparent diversity in that particular period/area is due to the presence of many miscellaneous and lesser abundant minor varieties that are absent in other contexts. However, there was a much greater probability that those rarer materials would be recovered in Period 3C levels on E-ET simply because 60% of the dateable assemblage belongs to that period and 80% of that comes from those mounds. When a similar amount of strata is eventually unearthed for other contexts it is quite probable that many of the scarcer varieties also will be encountered in them. Of course, some of those miscellaneous rocks and minerals actually may have been used for the first time by Harappans dwelling on Mounds E-ET during Period 3C. However, because of the small number of artifacts (all but one of the miscellaneous varieties is represented by three or fewer examples) and the clear bias in the assemblage distribution toward that particular area/period, such an interpretation would be rather tenuous indeed. Convincing evidence for *genuine* variations (i.e., those stemming from the behaviors of Harappans) between sub-

assemblages from different spatial and temporal contexts is better sought by examining varieties for which a much greater number of examples have been recovered.

The five major rock and mineral varieties at Harappa are present in all of the site's chronological phases. The few spatial contexts where some have not been found (such as the absence of siliciclastic rock artifacts on Mound ET during periods 2 and 3A) are, not surprisingly, those areas where limited exposures have produced extremely small sub-assemblages. Examples almost certainly will be found in those areas when more excavation takes place and, therefore, I believe it can be safely stated that Harappans of all periods and parts of the site probably had access to each of these material varieties. Possible temporal and spatial variations in the use of certain types of each of the major rock and minerals varieties are explored in upcoming chapters.

Many of the minor rock and mineral varieties display clear spatial and temporal variations, some of which are likely genuine, others of which are probably not. The uneven distribution through the assemblage of certain less abundant minor varieties, such as lead and serpentine, likely relates to the same issue of low recovery probability that affects the miscellaneous varieties. Similarly, the absence of nine of the twelve minor varieties from Period 3B contexts on Mound AB is almost certainly a result of sample size (only around 6% of the dateable assemblage from that period belongs from Mound AB – refer to Figure 4.15). Materials like gold, lapis lazuli, gypsum (alabaster), igneous-metamorphic rocks and ochre minerals each seem to have been used in all chronological phases and in most areas of the site. On the other hand, the "Ernestite," vesuvianite-grossular and limestone sub-assemblages are concentrated in certain contexts in ways (previously noted in this chapter)

and, importantly, *in amounts* that suggest the use of these materials was genuinely variable over time and space at Harappa. Further details relating to the use patterns of these three varieties of stone are featured in the upcoming chapters devoted to them.

Interpretation of the rock and mineral assemblage's composition and variability

In this final section, I consider the composition and variability of Harappa's rock and assemblage as a whole in relation to the three lines of inquiry outlined in Chapter 1.

Who in the ancient Greater Indus region or beyond were the residents of Harappa interacting with when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/acquisition networks? It was not the purpose of the chapter to make the provenience determinations necessary to link stone and metal artifacts from Harappa to their probable geologic sources. However, much can be still be learned about the possible extent and direction of the acquisition networks in which the site's residents participated by examining where potential raw material sources occur in relation to the site and to each other. Also, the geologic occurrences of at least one material variety – lapis lazuli, are sufficiently restricted enough that it is possible to confidently propose the existence of a specific source-to-site network during the periods in which it is present.

For her study of resource access and inter-regional interaction in the ancient Indus region, Marcia Fentress created a map of northwestern South Asia (Fentress 1976: Map 7) that is useful for conceptualizing distance/direction relationships and possible travel times between major Indus cities on the alluvial plains and the surrounding highland regions where rock and mineral resources occur. On it she placed concentric circles extending outward from Harappa and Mohenjo-daro at intervals of 100, 300 and 500 kilometers.

Using the same distance intervals centered just on Harappa, I have created a modified version of that map (Figure 4.13) on which numbers and symbols (corresponding to the varieties listed in the first column of Figure 4.12) are placed that identify the *nearest* locations where each of the rock and mineral varieties (and a few important macroscopically distinct sub-varieties or *types*) recovered at the site can be found. Half of them occur within a 300 km radius (around a 10-day walk in Fentress's estimation) and most of the rest are located within 500 km (≈ 20-day walk). Only for lapis lazuli, turquoise and the carnelian variety of agate would it have been necessary to travel farther than that. Most significantly, all of the nearest sources are located within a broad, semi-circular zone that begins directly west of Harappa in the Sulaiman Range and extends through regions to the north and northeast of the site. It should be stressed that the locations noted are not necessarily the sources that Harappans used (not all are the most accessible or the ones that contain the best quality material). They are the closest, however, and plotting them on the map in this way clearly illustrates how they are concentrated in the highland areas west and north of the upper Indus Basin. In terms of simple site-to-*potential*-source distance, Harappa is most decidedly oriented in these directions. It is, therefore, quite reasonable to expect that many of the rock and mineral varieties recovered at the site may have been originally derived from sources within this zone. I believe one variety – lapis lazuli, almost certainly was.

In Appendix 4.4, I argue that the Badakhshan area deposits of northern Afghanistan were the sole sources of lapis lazuli for consumers in ancient South Asia. Some degree of interaction between that source region and the Punjab from the fourth through second

Figure 4.13: Map showing the *nearest* sources of the major, minor and miscellaneous rock and mineral varieties found at Harappa (numbers and symbols correspond to varieties listed in column one of Figure 4.12).



millenniums BC second is, therefore, indicated by the presence of artifacts made of this stone in every one of the Harappa's chronological phases and sub-phases. Whether or not that interaction was direct or indirect and the route(s) along which it occurred is unclear. During the Early Harappan periods (ca. fourth and early third millenniums BC), residents of Harappa may have acquired lapis lazuli indirectly through long-distance trade with Helmand Tradition peoples, such as those at Shahr-i-Sokhta, who clearly seem to have been involved in its processing and transportation at that time (Tosi 1974a). The presence of Indus Civilization peoples at Shortughaï (Francfort 1989) in northern Afghanistan might well indicate that Harappans had direct access to that material during Period 3 (although the site was actually several hundred kilometers downstream and a few thousand meters below the actual deposits). Regardless of how it was acquired or how much was recovered, lapis lazuli is present throughout the sequence at Harappa and, because it was almost certainly from a source to the north of the site, it opens the possibility that many other rock and mineral resources were also being obtained from sources in that general direction.

How did the patterns of inter-regional interaction/acquisition exhibited by residents of Harappa change over time? Once again, it was not the intent here to make the provenience determinations necessary to diachronically examine patterns of interaction. Comparing assemblage compositions from period to period, however, gives the impression that, in general, there was not a great deal of change over time in the basic suite of materials used at Harappa. Dilip Chakrabarti's assertion (1998: 51) that there was "hardly any major change" in basic suite of raw material types used by Early Harappan and Harappan peoples basically holds true – at least at Harappa itself. The abundant varieties

are present throughout the site's entire sequence while less abundant ones likely vary because of low probability of recovery. Exceptions may be limestone, "Ernestite" and vesuvianite-grossular, the use of which seems to have been most intense during periods 3B and 3C. The reasons for this have been or will be discussed but, suffice to say, I do not think they have to do with newfound access to the regions where those materials occur. Rather, their use likely relates to changing cultural preferences (discussed in Chapter 11 for limestone) or technological innovation (the development of "Ernesite" drills).

Did synchronic variations in patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa? It appears that, by and large, people living in all parts of Harappa had access to the same varieties of rocks and minerals. This is *not* to say that they were acquiring them from the same sources or that they were using them in the same way; only that copper, steatite, chert, alabaster, etc, etc, are pretty much found in all parts of the site. Most instances where a particular material is absent from a mound is likely due to low probability of recovery for less abundant varieties in areas that have not been as extensively excavated. Vesuvianite-grossular and "Ernestite," which are concentrated on mounds E-ET, again seem to be exceptions. This may indicate that access to these particular materials was controlled by the residents of those areas (this issue is returned to again in chapters 9 and 13).

Chapter conclusion

Harappa's large and diverse rock and mineral assemblage has been organized and examined on a broad scale. In the next eight chapters, I attempt to identify the inter-regional interaction networks through which specific material varieties were acquired.

Chapter 5

Grindingstone acquisition networks

Chapter 5 – Grindingstone acquisition networks

Chapter introduction – The importance of grindingstones

Groundstone implements are, in terms of total weight, by far the most abundant kind of stone artifact found at Harappa. Included in this category are querns, mortars, mullers, pestles, whetstones, burnishers and adzes. Examples have been recovered in abundance from every chronological phase and on every habitational mound at the site. The only lithic categories containing more individually tabulated artifacts are those for steatite, chert and agate, which is certainly due in large part to the fact that a great deal of debitage is generated in the process of turning those raw materials into finished products. In this chapter, I examine the networks through which residents of Harappa acquired the largest, heaviest and perhaps most important kinds of groundstone implements – the querns and mullers essential for both processing staple grains and many craft activities.

Preparing cereals for human consumption is a multi-stage procedure that usually involves several different kinds of implements. Evidence for cereal processing at Harappa mainly exists in the form of stone querns and hand mullers. Other implements used may have been made of perishable materials that have not survived. The use of wooden mortars and pestles to de-husk cereals by pounding prior to further processing with stone querns is documented in Egypt during this period (Nesbit and Samuel 1996: 51-53). The prevalence of querns and mullers at the site might reflect the differential preservation of processing implements and/or that some processing stages took place away from of the city. Querns and mullers were, nevertheless, indispensable tools for preparing staple cereals (and many other foods) and so having a reliable supply of them would have been especially critical to

the development and maintenance of an urbanized society supported by agricultural surplus.

The role of craft activities in the economic and political development of complex societies in general (Costin 1991; Helms 1993) and the Indus Civilization in particular (Kenoyer 1989, 1992a) cannot be underestimated. It is therefore important to note that querns and mullers were also necessary for processing a range of non-consumables such as wood, shell, bone, hide and minerals (Dubreuil 2004). In a burgeoning center of craft production like Harappa a reliable supply of these implements would have been essential.

Querns and mullers (hereafter referred to together as "grindingstones") are the largest and heaviest utilitarian artifacts found at Harappa. Some of the few complete querns that have been recovered weigh in excess of 20 kg. Transporting these bulky items from distant sources to the site in the amounts necessary to fulfill the requirements of a growing urban population very likely would have required some form of organized effort. It certainly would have demanded an increasing expenditure of energy over time. When that reality is considered together with the requisite need for grindingstones to process staple foods and in craft production (plus the fact that there are no local stone sources whatsoever), it makes this category of artifact an excellent one with which to investigate issues relating to economy, transportation capabilities and early urban lifeways at Harappa.

I begin by first examining the regions in and around the upper Indus Basin that would have been the most likely sources of the grindingstones used at Harappa. Then I provide the details and results of a large-scale study in which geologic materials from those sources were visually compared to grindingstones recovered during excavations and

surveys at the site. Lastly, I examine the geologic provenience determinations made in that study in relation to Harappa's location, chronological sequence and spatial layout.

Potential grindingstone sources in and around the upper Indus Basin

Querns and mullers can be fashioned out of different varieties of geologic material. At Harappa grindingstones made from sandstone or quartzite were most common, but other sub-varieties of igneous and metamorphic rocks were also used. In this section, the potential grindingstone sources of the upper Indus Basin are reviewed in order of their proximity to the site. Multiple locations in each of the source areas discussed below were visited for this study. Samples representing the range of material sub-varieties present at those locations were collected and stored at Harappa for eventual comparative studies. All sources, regions and sites discussed in this chapter are identified on Figure 5.1.

The Kirana Hills

The Kirana Hills would have been nearest source of grindingstone (or of any variety of stone for that matter) available to residents of Harappa. These Precambrian outcrops emerge out of the alluvial plain near the center of the Ravi-Chenab doab, 120 km to the northeast of Harappa at Shah Kot and continue intermittently to around Sargodha, 150 km due north of Harappa in the Jhelum-Chenab doab. They are composed mainly of metasedimentary rocks (quartzites, conglomerates and slates) but intrusive bodies of igneous materials such as andesite, dolerite, rhyolite and/or volcanic tuff also occur (Alam et al. 1992). In the Gazetteer of the Jhang District (Punjab Government 1884: 15) it was reported that there were several quarries for "millstones, pestles and mortars" around Chiniot, near the point where the Chenab River passes between several Kirana outcrops.

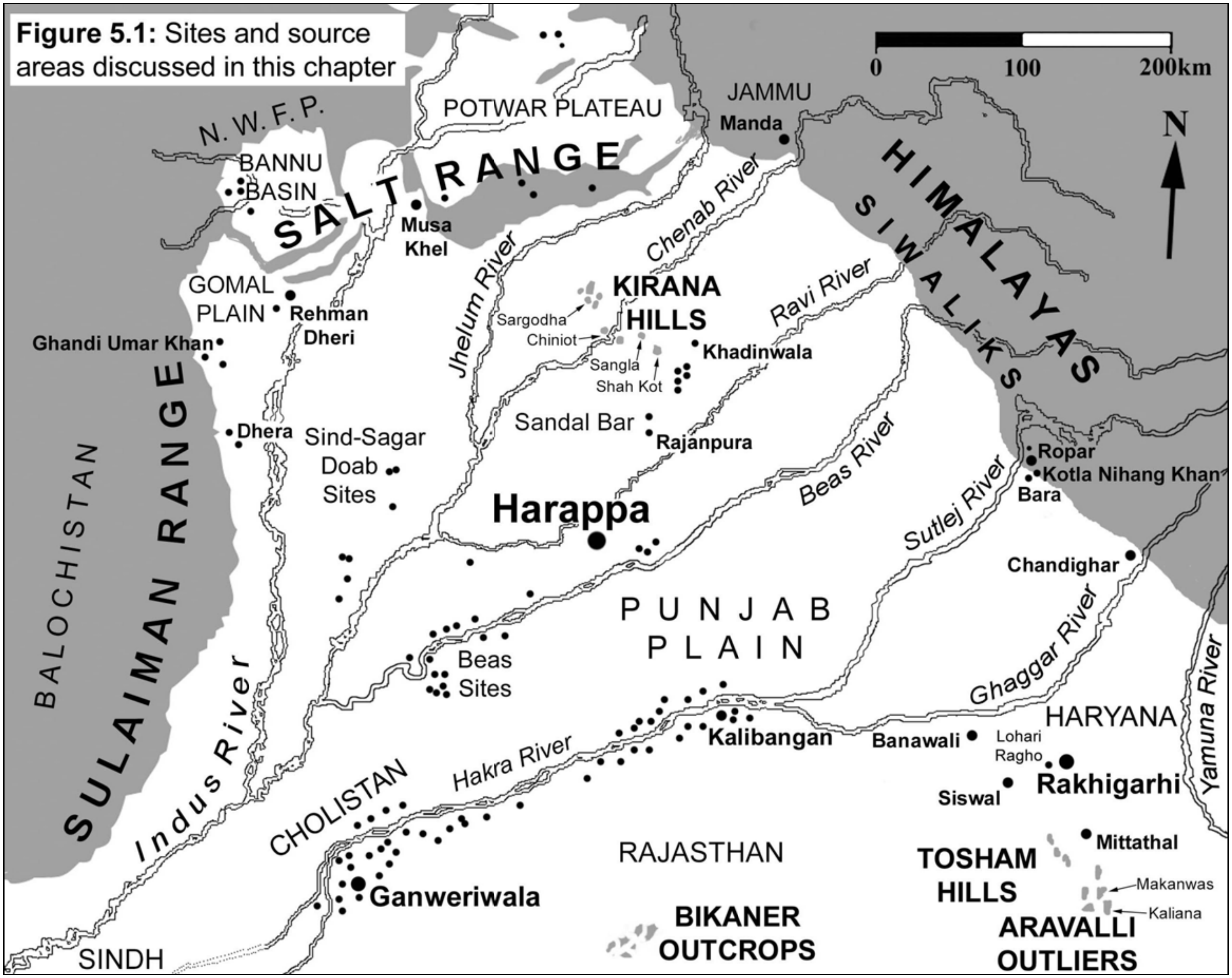


Figure 5.1: Sites and source areas discussed in this chapter

The Sulaiman Range

A nearly complete sequence of Jurassic to Pleistocene sedimentary rocks can be found beginning 220 km due west of Harappa in the extensive south-to-north oriented Sulaiman Range (Akhtar and Masood 1991: 1). The Pab Formation, with its thick beds of tough sandstone-quartzite, dominates the range and is a major source of raw material for the large rotary millstones used in many parts of Pakistan today (*personal observation*). Monsoonal hill torrents, "heavily laden with detritus" (Punjab Government 1898: 2-3), have resulted in the formation of massive alluvial fans and boulder beds that extend along the base of these mountains.

The Salt Range

The Salt Range, rising 225 km north of Harappa just beyond the Jhelum River, marks the abrupt end of the Punjab Plain in the north. Material for grindingstones could have been obtained from any number of the sandstone formations or boulder beds found here (Shah 1980). The pinkish-red to maroon colored sandstone of the Kherwa formation, located along the southern base of the range, would have been the most accessible to plains dwellers. I have observed grindingstone fragments composed of Khewra sandstone at the Early Harappan to Harappan period site of Musa Khel (Dani 1971: 32), located less than four kilometers to the southwest of the Salt Range.

Bikaner area outcrops

Approximately 250 km directly south of Harappa, rocks of Tertiary age begin to rise out of the alluvium in the vicinity of Bikaner in northwestern Rajasthan. Outcrops of sandstone, shale and limestone (Pareek 1984) intermittently break or occur immediately

below the surface of Quaternary era sand flats and dunes (*personal observations*). Although most of the stone here is unsuitable for grinding purposes (being highly ferruginous and friable) I did observe some thin beds (≈ 10 cm thick) of fairly tough, coarse grained sandstone that was not unlike material used today to make rotary querns farther to the south in the Jaisalmer district of Rajasthan.

The Foothills of the Himalayas

The Himalayan foothill zone begins approximately 300 km northeast of Harappa. Extending continuously from the Potwar Plateau in northern Pakistan all the way to eastern India, this zone primarily consists of the sedimentary rocks of the Siwaliks and Outer Himalayas (Kumar et al. 1991: 1-2). Cobbles of igneous and metamorphic rocks, more characteristic of Inner Himalayan formations can, nonetheless, occasionally be found in the beds of rivers passing through this zone (*personal observations*).

Tosham Hills and Aravalli Outliers

Nearly 350 km southeast of Harappa, in southern Haryana, India, a series of igneous outcrops emerges from the plains in the vicinity of Tosham. Most of the hillocks in the area are composed primarily of Precambrian grey granite (Grover and Kumar 1980). One of them (Tosham Hill) contains a rich polymetallic ore deposit and has been proposed as a possible source of tin for the Indus Civilization (Kochhar et al. 1999).

Thirty kilometers farther southeast of the final Tosham outcrops are the western-most outliers of Delhi Quartzite, a formation which makes up large parts of the northern Aravalli Mountain Range. Unlike most heavily metamorphosed Delhi quartzite, which typically has a silicious or "glassy" texture, the material found in these particular outliers

has a sandy texture and, in a few places, an unusual "flexible" quality that actually permits the stone to be significantly deformed before it breaks (Pande and Gupta 1969).

Determining the geologic provenience of Harappa's grindingstones

A large-scale geologic provenience investigation of querns and mullers was initiated following a preliminary study of grindingstone artifacts that took place during the HARP's 2000-2001 field season. The preliminary study had indicated that there were probably several distinct *types* of grindingstone present within the rock and mineral assemblage at Harappa. In this chapter, I use the word "type" rather than variety or sub-variety to refer to grindingstone material that has been defined based on its visual appearance and/or the location/geologic formation where it occurs (siliciclastic sedimentary rock is a variety, sandstone is a sub-variety and Pab sandstone is a type). Examples of what appeared to be the different types of grindingstone from Harappa were included in the "traveling" set of archaeological samples (discussed in Chapter 2) that was taken to institutions around Pakistan for comparative study. There they were evaluated by geologists with years of field experience in the potential source regions. Using their recommendations and identifications as a starting point, I undertook numerous field excursions in Pakistan and India over the next four years for the purpose of collecting comparative geologic samples. In addition to the six regions discussed in the preceding section, samples were collected from sources in Balochistan, Sindh, Gujarat, Jammu, the NWFP and Pakistan's Northern Areas as well as regions elsewhere in Rajasthan and Indian states in the western Himalayas. All samples collected in the field were brought to Harappa and, over time, a large set of geologic comparative materials was compiled.

By early 2004 the geologic sample set was reasonably comprehensive and so a systematic comparison with grindingstone artifacts from Harappa could begin. Some form of quantitative analysis focusing on geochemical properties (isotopic compositions, elemental concentrations, etc) was undertaken for most of the material varieties examined in this dissertation. Several factors made a study of that kind unfeasible for grindingstones: no analytic instrumentation was available at Harappa; analyzing the entire assemblage would have been prohibitively expensive; and physically removing material from each artifact for destructive analysis elsewhere was not possible. A series of petrographic thin sections from a selective sample of Harappan grindingstones representing each major material type were made at the Pakistan Museum of Natural History and will eventually be used to supplement this study. However, the provenience determinations made here were based solely on the qualitative comparison of the macroscopic characteristics of artifacts and source samples. Although visual analysis of stone artifacts, when used alone, does have limitations (Luedtke 1979: 745-46), it is rapid, cheap, non-destructive, can be done in the field on a large-scale and sometimes produces results that are as good or better than those obtained using more sophisticated methods (Moffat and Buttler 1986: 14).

All querns and mullers (whole and fragmentary) recovered from excavations and surveys at Harappa (Appendix 5.1) along with those from previous excavations stored in the site museum's reserve collection (Appendix 5.2) were individually examined. In total, 2586 grindingstone artifacts were compared with geologic source samples and assigned a provisional geologic provenience based on an assortment of qualitative physical criteria including rock sub-variety, color, texture, grain size, patterning, visible inclusions, degree

of silicification and toughness. Those that could not be confidently assigned a provenience using these criteria were classified as "unknown."

The geologic provenience composition of Harappa's grindingstone assemblage

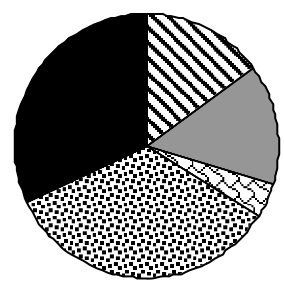
The overall composition, in terms of geologic provenience, of the grindingstone assemblage at Harappa is displayed, without reference to context or period, in Figure 5.2. Before proceeding, however, it is necessary to explain the manner in which the percentages found in the tables and charts used in this chapter were generated. Harappan grindingstones were tools that appear to have been used, broken, re-fashioned and re-used repeatedly. Thus, nearly all of the grindingstones recovered are in a fragmentary state. Some are almost complete – that is, they may only be chipped or slightly broken. However, even though multiple fragments that belong to the same implement have been refitted whenever possible, most of the assemblage consists of incomplete pieces what were clearly larger implements at one time. So this raises the question – when calculating the amounts of different grindingstone types present at Harappa, is it more suitable to generate percentages based on the number of individually tabulated artifacts or the total weight of artifacts in a particular category? For some of the figures below both methods are presented and it is evident that, in most instances, the resulting percentages are not dramatically different. Ultimately, however, it was decided that generating percentages of material types present at the site based upon weight, rather than on the number of individual fragments, would more accurately reflect the degree to which material from a defined source was being utilized in a certain area of the site or during a particular period. Nevertheless, the total numbers of artifacts present in each category are listed in the tables

that accompany the figures so that anyone wishing to evaluate the data by tabulated artifacts may do so. Nearly seventy percent (68.1% by weight and 69.5% by number) of all querns and pestles at Harappa could be confidently assigned to one of the following four material *types*, which are now discussed in order of decreasing abundance: Pab sandstone, Delhi quartzite, gray sandstone and Kirana Hills stone.

Figure 5.2: Overall composition of the grindingstone assemblage at Harappa (without reference to period or context)

Legend: Delhi quartzite; Gray Sandstone; Kirana Hills stone; Pab sandstone; Unknown provenience

Percentage calculated by weight	weight (kg)	portion of entire the grindingstone assemblage
Delhi quartzite	237.0	15.1%
Gray sandstone	231.9	14.7%
Kirana Hills stone	64.2	4.1%
Pab sandstone	539.0	34.3%
Unknown	501.2	31.9%
assemblage total	1573.3	100.0%



Percentage calculated by number of objects	number of objects	portion of entire the grindingstone assemblage
Delhi quartzite	534	20.6%
Gray sandstone	171	6.6%
Kirana Hills stone	314	12.1%
Pab sandstone	777	30.0%
Unknown	790	30.5%
assemblage total	2586	100.0%

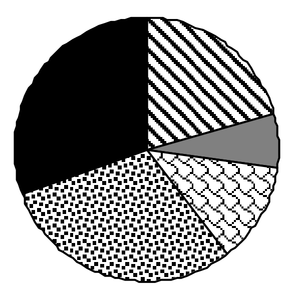


Figure 5.3: The Pab Formation, details of the types of sandstone found in it and examples of Pab sandstone artifacts from Harappa and other sites.



A. Exposed section of Pab Sandstone in the Sulaiman Mountains near Ft. Munro, D,G. Khan District, Punjab.



B. Brown (left) and speckled (right) types of Pab sandstone in the Sulaiman Range.



C. Pab sandstone saddle quern (#982) from M.S. Vats' excavations at Harappa.



D. Pab sandstone muller (H95/5802-8) from Harappa, Mound ET, Period 3C



E. Pab sandstone hand muller from Mohenjo-daro. Department of Archaeology and Museums Excavation Branch Collection



F. Pab sandstone quern fragment on the surface at the Harappan Period site of Ganweriwala, Cholistan. [10 cm scale]

Figure 5.4: Delhi quartzite outliers in southern Haryana, detail of stone types found there and examples of Delhi quartzite artifacts from Harappa and other sites.



A. Delhi Quartzite outliers near Kaliana, Bhiwani District, Haryana.



B. Detail of Delhi quartzite at Kaliana.



C. Delhi quartzite saddle quern fragment (H96/7205-2) from Harappa, Mound AB, Period 3 or later.



D. Delhi quartzite flat quern (H95/5181-1) from Harappa, Mound E, Period 3C.



E. Delhi quartzite quern from the Early Harappan site of Siswal, Hissar District Haryana. This artifact was unearthed by and is in the possession of, the farmer whose fields now cover the surface of the site.



F. Delhi quartzite fragment on the surface of the Harappan site of Kalibangan, Hanumangarh District, Rajasthan.

Figure 5.5: Gray sandstone artifacts at Harappa, rivers draining the Himalayas, cobbles found in their beds and gray sandstone artifacts at other sites.



A. Gray sandstone saddle quern from Vats' excavation at Harappa.



B. Gray sandstone muller (H94/5502-61) from Harappa. Mound ET, Period 3B



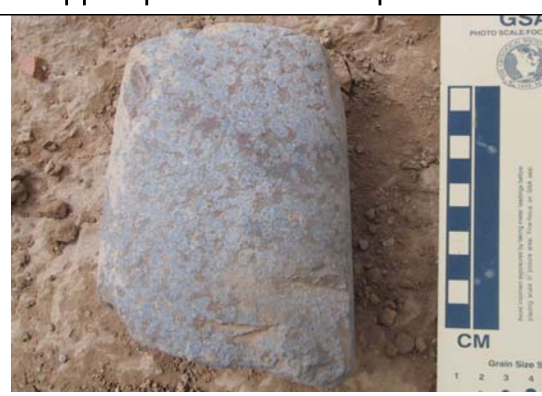
C. Cobbles in the bed of the Ghaggar River at the point near Chandigarh where it leaves Himalayas



D. Gray sandstone cobbles in the bed of the Sutlej River, 2km from the Harappan period site of Ropar.



E. Gray sandstone saddle quern on the surface of Harappan period site of Ropar, Ambala District, Punjab.



F. Gray sandstone muller on the surface of Harappan period site of Banawali, District Hissar, Haryana.

Figure 5.6: Kirana Hills outcrops, details of two types of stone found there and examples from Harappa.



A. Kirana Hills outcrop at Sangla, District Sheikhupura, Punjab.



D. Kirana Hills outcrops astride the Chenab River at Chiniot, Punjab.



B. Detail of the medium to fine-grained quartzite found at Sangla Hills.



E. Detail of the coarse-grained, conglomeritic quartzite found at the Chiniot area outcrops.



C. Fragment (H98/8590-3) of Kirana stone from Period 1 at Harappa similar in appearance to the Sangla sub-type.



F. Fragment (H89/1197-12) of Kirana stone from Period 2 at Harappa that looks similar to the Chiniot sub-type.

Pab sandstone

Sandstone from the Pab Formation (Figure 5.3, A) is, by weight (34.3%), the most common type of raw material in Harappa's grindingstone assemblage. This Cretaceous sandstone has a sugary texture and macroscopically grades from solid brown to a distinctive gray-white color with small (< 3mm) regularly spaced brown patches (Figure 5.3, B). The grindingstones at Harappa that have been categorized as Pab sandstone, two of which can be seen in Figure 5.3 C & D, are highly variable visually. The majority are grey-white with the distinctive brown spots or speckles. In other examples the characteristic spots are muted and there is a prominent brown, wavy, banded pattern. Some simply have a uniform brown color. In numerous cases two or more such visual patterns are present *in a single grindingstone* – sometimes as sharply defined components and at other times gradually grading into one another. After inspecting a range of this material in the field and examining (and re-examining) nearly 800 examples at Harappa, I felt confident in my ability to recognize these variations and correctly assign material type and provenience. Although this method of categorization is admittedly subjective, I would argue that the results it produces are sound given the large number of samples and the striking visual and tactile differences between materials in each type-provenience category.

The most extensive and well-developed sequence of Pab sandstone occurs beginning 220 km due west of Harappa in the Sulaiman Range (Kassi et al. 1991). After a break of nearly 300 km beginning near Balochistan's northern border with Sindh, the Pab Formation appears again over 600 km to the southwest of Harappa in the Las Bela and Khuzdar districts of southern Balochistan. The assumption made here is that the majority

of Pab grindingstones identified at the site probably derived from the closer occurrence in the Sulaimans. Quarrying grindingstone directly from formations in the mountains themselves would have almost certainly been unnecessary during the proto-historic period as large cobbles suitable for querns and pestles could have easily been obtained from the alluvial fans or stream beds of the foothills that line the range. For this reason it is difficult to state precisely at what point or points along that approximately 300 km long north-south running mountain range that Pab sandstone used at Harappa was obtained. The site of Dhera, which has cultural affinities with Early Harappan cultures of the Punjab Plain and the adjacent Balochistan highlands, is located in this foothill region adjacent to a cobble-filled perennial hill torrent emanating from the central part of the Sulaiman Range (Siddique 1996). I observed Pab sandstone querns and mortars in a recent collection from the Harappan Period site of Ghandi Umar Khan (Khan et al. 2000), which lies near the foothills of the northern end of the Sulaiman Range.

The sugary texture and toughness of Pab sandstone makes it exceptionally well suited for grinding purposes. It is widely used for this purpose in modern Pakistan and "is also exported to Arabian countries" (Khan, M.A. et al. 1991: 223). During a visit to the city of Mardan in the NWFP, I visited a workshop where rotary millstones were being carved. Despite the fact that there are no lack of local stone formations in the NWFP from which millstone material could have been acquired, I was told that the stone they were using – Pab sandstone, was transported over 300 km (as the crow flies) from the Ft. Munro area of the Sulaiman Range. The unmatched quality of this particular material made transporting the heavy stone long distances and in large quantities worth the effort and expense.

That same sentiment may have held true in Harappan times as well. I have noted Pab sandstone in collections made by Dr. Rita Wright from the Early Harappan (Kot Dijian) Period and Harappan Period sites found along the old bed of the Beas River (Wright et al 2002; Schuldenrein et al. 2004). The majority of the grindingstones from Mohenjo-daro (Figure 5.3 E) that are stored in the collection of the Department of Archaeology and Museums, Government of Pakistan's Excavation Branch in Karachi are made of Pab sandstone. Similarly, most of the grindingstones that I encountered on the surface of the as yet unexcavated Harappan period city of Ganweriwala (Figure 5.3 F) in the Cholistan region were composed of Pab sandstone. Fully one-third of all grindingstones recovered at Harappa are Pab sandstone and I suspect the same may be true when the full assemblages at Mohenjo-daro and Ganweriwala are examined as well.

Delhi quartzite

The second most common type of grindingstone at Harappa (15.1% by weight) appears to be the type of Delhi quartzite found only in the westernmost outliers of the Aravalli Mountains, located in southern Haryana (discussed above). Unlike the glassy, highly silicified gray-colored material that is typical of Delhi quartzite elsewhere in the Aravallis, the stone from these outcrops in the vicinity of Kaliana and Makanwas villages (Figure 5.4: A) in the Bhiwani district has a sugary texture, is red-pink to pinkish gray in color and is crisscrossed with thin hematite and quartz filled fractures (Figure 5.4: B). None of the other geologic formations immediately surrounding the upper Indus Basin contain material that even remotely resembles this distinctive type of quartzite. Grindingstones made of this stone at Harappa (Figure 5.4: C & D) are easily identifiable.

In certain places, the Delhi quartzite from these Aravalli outliers has an unusual "flexible" quality that may make it especially good stone for use as querns and mullers. Describing stone from the Kaliana outcrop, the geologists Pande and Gupta wrote:

> If one of the specimens which exhibits this peculiarity in any marked degree be examined, it will be found to yield with readiness to any external force applied, and it can be stretched, compressed or bent in any direction with the greatest ease up to a certain point beyond which the force is released along fractures (Pande and Gupta 1969: 589).

A grindingstone composed of Delhi quartzite with some degree of flexibility may be less likely to fracture under the stress of grinding and pounding than would a more ridged type of sandstone-quartzite. At Kaliana village today there is a small industry devoted to creating mortars, pestles and querns using stone from the local outcrop (*personal observation*). In future studies it would be very informative to conduct mechanical stress tests comparing this and the other types of grindingstones as a way to gage the "quality" of the different materials used at Harappa. Poor quality (a tendency to fracture under the stress of grinding and pounding) may perhaps be one of the reasons why (as we shall see below) certain types of grindingstone material become less represented in Harappa's assemblage over time.

The northernmost of these Delhi quartzite outliers is located 389 km southeast of Harappa but is only 29 km south of the site of Harappan period site of Mitathal (Bhan 1969). I have observed this type of quartzite in abundance on the surface of Mitathal and at several other Early Harappan and Harappan period settlements that lay between the Delhi

outliers and Harappa including Banawali (Bisht 1982), Siswal (Figure 5.4: E) (Dikshit 1984) and Kalibangan (Figure 5.4: F) (Thapar 1979). The Harappan period city of Rakhigarhi (Nath 1998) is located 73 km north of these outcrops. A large mortar and several querns recovered from that site are on display at the National Museum in New Delhi and also appear to be composed of the Kaliana area type of Delhi quartzite.

Gray sandstone

The next most common type of grindingstone at Harappa (14.7% by weight) is composed of extremely dense and tough gray sandstone (Figure 5.5 A & B). It is typically medium-to-fine-grained and likely came from one of two regions.

The Upper Cretaceous Mughal Kot formation occurs intermittently along the length of the Sulaiman Mountains but is most well developed approximately 300 km northwest of Harappa in the northernmost part of that range (Kassi et al. 2000; Cheema et al. 1977). Mughal Kot sandstone is, in places, very dense and gray. I have observed grindingstones composed of such material on the surface of and/or in collections from Early Harappan and Harappan Period sites just east of the Sulaiman Range on the Gomal Plain such as Rehman Dheri (Durrani 1988) and Ghandi Umar Khan (Khan et al. 2000). The Mughal Kot Formation, where it is exposed, lies adjacent to the Pab Formation. It is, therefore, possible that both types of sandstone could have been collected from the same locations.

Gray sandstone eroded from formations in the Siwaliks foothills and Lower Himalayas (Srikantia and Bhargava 1998: Chapter 5) can also be obtained beginning 350 km east-northeast of Harappa in the beds of Chenab, Beas, Sutlej and Ghaggar rivers (Figure 5.5 C & D) at the places where they meet the Punjab plain (*personal observation*).

Importantly, several Harappan and/or Early Harappan settlements are located near these debouchures. The site of Manda is located in the Siwalik Foothills of Jammu at the northernmost navigitable point of the Chenab River (Joshi and Bala 1982). Harappan remains were also unearthed at Chandigarh, not far from where the Ghaggar River meets the plains (IAR 1985-86: 15). Ropar, Bara, Kotla Nihang Khan and Dher Majra are all proto-historic sites found within 10 km of the point at which the Sutlej River leaves the foothills (Prüfer 1956; Sharma 1982). Most of the grindingstones evident on the surface at Ropar (Figure 5.5 E) and on display in its site museum are composed of gray sandstone (*personal observation*). Cobbles of this material could have easily been transported from all of the sites/areas mentioned downstream to Harappa and other plains settlements via the rivers of the upper Indus Basin. In fact, I have also observed gray sandstone grindingstones on the surface (Figure 5.5 F) of and/or in collections from the Harappan sites in Haryana including Banawali (Bisht 1982) and Lohari Ragho near Rakhigarhi (Garge 2006).

Mughal Kot sandstone and the gray sandstone cobbles found in the beds of rivers emanating from the lower Himalayas are too texturally and visually similar to make clear distinctions between them based on macroscopic examination alone. Thin sections of a small set of gray sandstone grindingstone fragments from Harappa have been made and future petrographic studies comparing them to material from the two regions may help to better resolve their provenience. However, given that Early Harappan and Harappan period sites lie in or adjacent to those regions and stone of this description is found at those sites, it is likely the case that gray sandstone from both regions are represented in Harappa's grindingstone assemblage. What is fairly clear is that such fine gray sandstone almost

certainly does not come from formations in the northern Aravallis or its outliers. I have not encountered any such material during the course of my field studies there, seen it mentioned in the geologic literature or heard it described when consulting with geologists who work in the northern Rajasthan or southern Haryana regions.

Kirana Hills stone

The final and least abundant overall by weight (4.1%) of the four major identifiable grindingstone material types at Harappa is stone from the Kirana Hills. Kirana Hills stone, in terms of grinding purposes, is of decidedly inferior quality when compared to the other three material types described above as it tends to be much more friable. Thus, it breaks easier and produces many fragments. This then is an instance where the choice to consider material usage by weight rather than by number of individual artifacts tabulated makes a significant difference in how the composition of the overall grindingstone assemblage appears. For example, gray sandstone is very compact and tough and many more complete or nearly complete artifacts of that type have been recovered as compared to Kirana stone artifacts, which are nearly always found as fragments. When judged by number of fragments present, Kirana stone accounts for 12.1% of the grindingstone assemblage, making it, instead of gray sandstone, which by number only accounts for 6.6% of the assemblage, the third most common type in the assemblage. Conceivably, the same amounts of both material types could have been brought to the site and used. However, use of the more friable Kirana stone would perhaps result in more individual pieces of debris. It is for this reason that in most cases I have chosen to consider grindingstone source usage by weight instead of number.

Regardless of its quality, stone from the Kirana Hills would have been by far the closest material of any kind available for residents of Harappa to use for grindingstones. The compositions and characteristics of the stone are variable from outcrop to outcrop (Alam et al. 1992). Two different sub-types seemed to have been in use at Harappa.

At certain outcrops, such as those found at Shah Kot, Sangla Hill (Figure 5.6 A) and some locations around Chiniot and Sargodha, a fine grained grey-green mottled, hematite-stained meta-quartzite is the dominant material (Figure 5.6 B). The grindingstone artifacts recovered at Harappa that are made of this material (Figure 5.6 C) are invariably fragmentary. No complete examples of querns or mullers have been found.

At several places in the Sargodha area and again in the hills straddling the Chenab River near Chiniot (Figure 5.6 D), quartzite occurs that is gray-red to purplish-gray in color and has a coarse, conglomeritic texture with small clasts of cherty material (Figure 5.6 E). Grindingstones made of this conglomeritic quartzite (Figure 5.6 F) are found more frequently at Harappa than are examples of the fine grained sub-type. Also, several examples of complete mullers and nearly complete querns made from conglomeritic Kirana stone have been recovered.

Although it would have taken a resident of Harappa several days to walk the 120 to 150 km distance to the Kirana Hills, there are a handful of Early Harappan and Harappan period settlements that are relatively close to that formation's southernmost outcrops. These include Khadin-wala (Dar 1983) and a cluster of eight other recently discovered proto-historic sites in the Ravi-Chenab doab or Sandal Bar (Qasim 2002), which are located 15 to 25 km south and west of the Shah Kot outcrop along what may have been the

former watercourse or a tributary of the Ravi River. Harappan peoples making a journey to and from the site of Manda in the foothills of Jammu via the Chenab would have passed between the outcrops in the Chiniot area. Kirana Hills stone seems to have also been transported to settlements in regions beyond Harappa. I have observed a numerous fragments of what appears to that material in Beas Survey (Wright et al 2002) collections from Early Harappan and Harappan Period sites along the old bed of the Beas River, some of which lie as far as 275 km away from the outcrops (Schuldenrein et al. 2004).

"Unknown" Provenience

Slightly more than thirty percent (31.9%) of the grindingstones in the assemblage could not be confidently assigned to any specific geologic formation based on macroscopic characteristics alone and so were categorized as having an "unknown" provenience. A great many of these were igneous and metamorphic rocks such as dense black basalt, gabbro, gneiss and diorite that are visually identical to other rocks of the same sub-varieties found in numerous regions surrounding the Indus Valley. Many examples of gray or pink granite grindingstone fragments were examined that could have been from the Tobra boulder beds of the Salt Range (Shah 1980: 12), the Nagar Parker outcrop of southern Sindh (Jafry and Ahmad 1991), outcrops in the Jhunjhunu district of northern Rajasthan (Basu 1982) or several other locations including the Tosham Hills. Likewise, the numerous highly silicified white quartzite cobbles encountered could have come from as near as the Dok Pattan Formation of the Siwaliks (Iqbal 1994) or one of several formations in the North Delhi Fold Belt of the Northern Aravallis (Sinha-Roy et al 1998: 129-140). Chemical composition, isometric dating of igneous rocks and/or petrographic analyses

may, in the future help, to resolve the geologic proveniences of many of these "unknown" types.

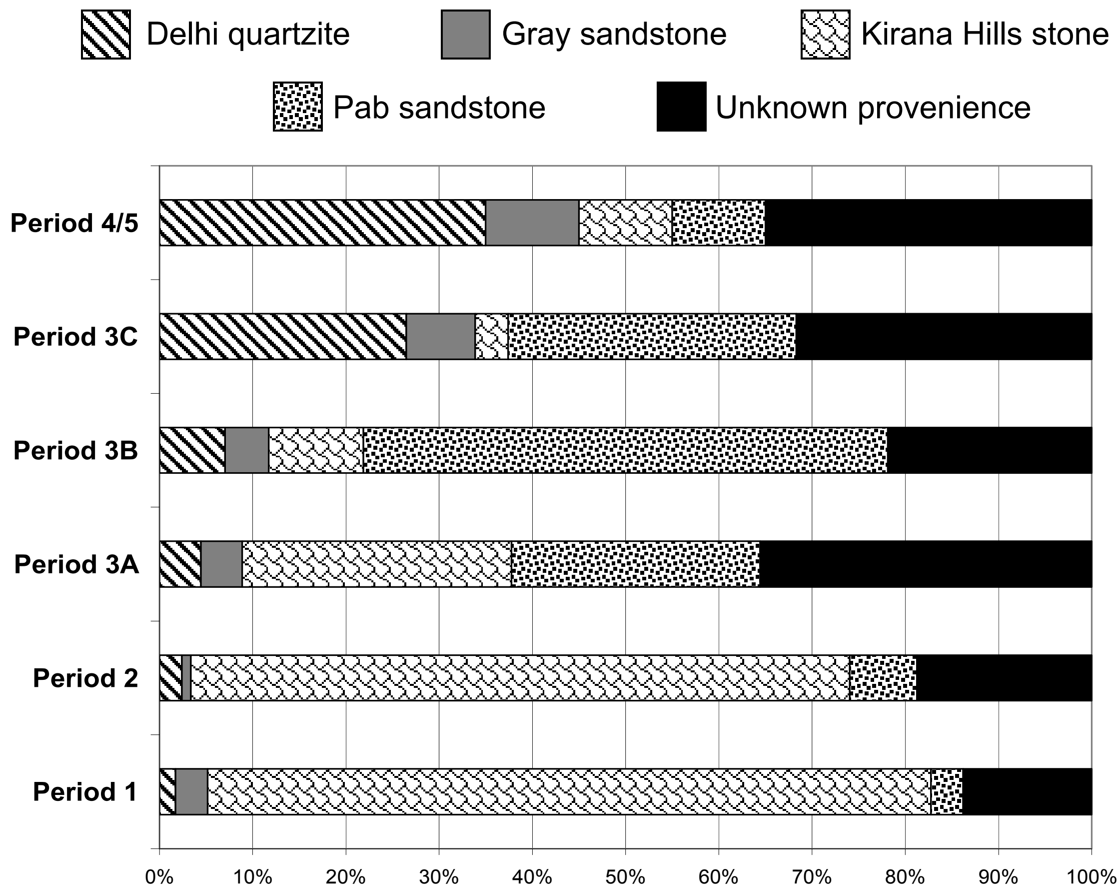
Diachronic and spatial variations in grindingstone source utilization at Harappa

Nearly 43% of the 2586 querns and mullers from Harappa evaluated in this study were recovered during surface surveys or came from disturbed or secondary contexts such as brick robber trenches or the sifting of back dirt piles from past excavations. However, 1475 of the grindingstones have been excavated from secure, stratified contexts spanning Harappa's five main periods of occupation. This assemblage essentially represents a 100% sample of grindingstone artifacts in excavated areas. With such a substantial dataset it is possible to address questions relating to diachronic and spatial variation in grindingstone source utilization at Harappa with a reasonably high level of confidence. In the following sections I use this dataset to investigate how acquisition patterns for this important utilitarian goods shifted as the site was transformed over time from a small village into a large urban center. I also investigate if variations in source utilization existed between the different habitation areas at Harappa during those periods (2 through 3C) from which grindingstones have been recovered from two or more of the site's mounds.

Site-wise diachronic trends in grindingstone source utilization

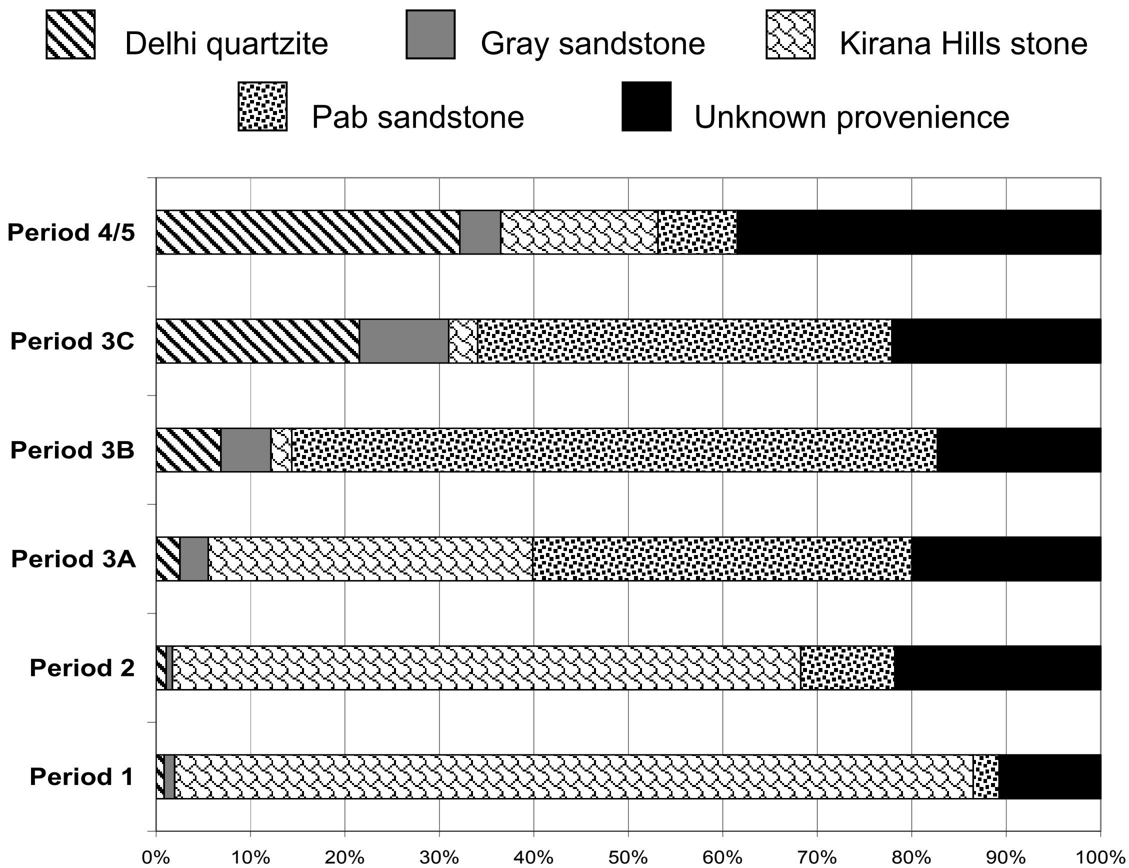
I begin with a presentation of the general diachronic trends in grindingstone source use for the site of Harappa as a whole (without reference to temporal trends on individual mounds). These trends have been calculated in two ways: by number of artifacts by period (Figure 5.7) and by total weight of all artifacts in each category by period (Figure 5.8). I present both methods here because, although they have produced some notably different

Figure 5.7: Grindingstone source utilization through time (percentage calculated by ***number of individual objects***)



	Period 1	*n =*	**Period 2**	*n =*	**Period 3A**	*n =*	**Period 3B**	*n =*	**Period 3C**	*n =*	**Period 4/5**	*n =*
Delhi quartzite	1.72%	*1*	2.40%	*5*	4.44%	*2*	7.03%	*9*	26.48%	*269*	35.00%	*7*
Gray SS	3.45%	*2*	0.96%	*2*	4.44%	*2*	4.69%	*6*	7.38%	*75*	10.00%	*2*
Kirana Hills stone	77.59%	*45*	70.67%	*147*	28.89%	*13*	10.16%	*13*	3.54%	*36*	10.00%	*2*
Pab SS	3.45%	*2*	7.21%	*15*	26.67%	*12*	56.25%	*72*	30.91%	*314*	10.00%	*2*
unknown	13.79%	*8*	18.75%	*39*	35.56%	*16*	21.88%	*28*	31.69%	*322*	35.00%	*7*
total	100%	*58*	100%	208	100%	*45*	100%	*128*	100%	*1016*	100%	*20*

Figure 5.8: Grindingstone source utilization through time
(percentage calculated by ***total weight*** of each type)



	Period 1 percentage (weight)	**Period 2** percentage (weight)	**Period 3A** percentage (weight)	**Period 3B** percentage (weight)	**Period 3C** percentage (weight)	**Period 4/5** percentage (weight)
Delhi quartzite	0.86% (80.2 g)	1.06% (397.0 g)	2.5% (313.4 g)	6.87% (4060 g)	21.54% (73902 g)	32.16% (988.5 g)
Gray SS	1.12% (104.3 g)	0.68% (253.4 g)	3.0% (374 g)	5.28% (3122.2 g)	9.45% (32413.7 g)	4.33% (133.2 g)
Kirana Hills stone	84.53% (7890.7 g)	66.51% (24819 g)	34.3% (4275.2 g)	2.22% (1311.6 g)	3.05% (10471.9 g)	16.66% (512 g)
Pab SS	2.74% (256 g)	9.95% (3714 g)	40.1% (4997.1 g)	68.34% (40378.1 g)	43.86% (150479.2 g)	8.37% (257.1 g)
unknown	10.75% (1003.7 g)	21.80% (8133.9 g)	20.0% (2486.8 g)	17.29% (10213.4 g)	22.10% (75817.57 g)	38.48% (1182.6 g)
total	100% (9334.9 g)	100% (37317.6 g)	100% (12446.5 g)	100% (59085.3 g)	100% (343084.4 g)	100% (3073.4 g)

compositional patterns during certain periods, the basic large-scale diachronic trends appear to be more or less the same using either weight or number for calculating use percentages. We see that the sources in the Kirana Hills are by far the most heavily utilized during the early pre and early urban periods (Ravi and Kot Diji Phases) but then appear to rapidly fall out of use starting in the fully urban period (Harappa Phase). Conversely, Pab sandstone utilization is sparse early on but increases significantly after the beginning of the urban phase. Very little Delhi quartzite is used as grindingstone at first but its overall proportion in the assemblage slowly and steadily increases over time. Gray sandstone seems to have always remained a relatively minor component of the grindingstone assemblage, never reaching 10% of the total during any period at Harappa.

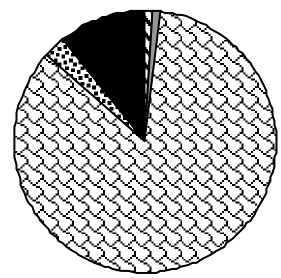
I now examine these trends in detail; phase by phase and mound by mound. I refer to the percentages calculated by total weight listed in Figure 5.7 when discussing site-wise geologic source or material type (source-type) grindingstone use patterns. When looking at differences in material use between habitation areas, I exclude grindingstone artifacts recovered from features of the site outside of the main mounded areas (such as the cemetery area or various Harappan period dumps) from consideration, even though they may be from secure and dateable contexts. All of the remaining percentages that I discuss in this section have been calculated by total weight of each material type and are listed in the accompanying figures.

Ravi Phase – Period 1 (ca. 3300 BC to 2800 BC)

At present, all of the grindingstone from the first occupational period at Harappa (Figure 5.9), the Ravi Phase, comes from excavation units in Trench 39 on the northern end

Figure 5.9: Grindingstone source utilization on Mound AB – **Period 1**
(percentage calculated by *total weight* of each type)

Mound AB	amount	weight (g)	percentage
Delhi quartzite	1	80.2	0.86%
Gray sandstone	2	104.3	1.12%
Kirana Hills stone	45	7890.7	84.53%
Pab sandstone	2	256	2.74%
Unknown	8	1003.7	10.75%
total	58	9335	100%



of Mound AB – although there is also evidence of a Ravi occupation in the northwest corner of Mound E (Kenoyer and Meadow 2000). During this initial phase the residents of the then village-size settlement (ibid.) acquired the vast majority (84.5%) of their stone for grinding purposes from the nearest sources in the Kirana Hills. Most of the remaining material (10.7%) recovered from this period is of unknown provenience. Some of these "unknowns" are mafic (dark colored due high magnesium and iron content) rocks like dolerite that could themselves come from the intrusive igneous bodies that also occur at places in the Kirana Hills. A few of examples of Pab sandstone, Delhi quartzite and gray sandstone are present in these early levels also. This indicates that, even at this initial stage, some degree of interaction was taking place with the distant regions to the west and east of Harappa where those material sources are found. By and large, however, it is clear

that during Ravi Phase Harappans were very much focused on utilizing the closest and, presumably, most accessible grindingstone sources.

Kot Diji Phase – Period 2 (2800 to 2600 BC)

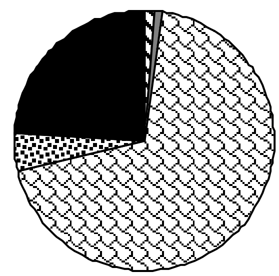
By the subsequent Kot Diji Phase, the site of Harappa and Harappan society were well on their way to becoming fully urban. The area of settlement grew to encompass all or most of Mound AB, Mound E and parts Mound ET (Meadow and Kenoyer 2001: 24). In total, 208 grindingstones have been recovered from trenches penetrating Period 2 levels in AB and E (Figure 5.10). Residents of the young city were now part of a cultural entity termed “Kot Dijian”, which extended from central Sindh in the south to the Potwar Plateau in the north (Mughal 1990a). Despite their increasingly social complexity and enlarged cultural horizons the majority of the grindingstone Harappans used (66.5%) was still obtained from the closest sources in the Kirana Hills. However, percentages of the other grindingstone types do begin to increase somewhat (Pab sandstone in particular grows to comprise nearly 10% of the Period 2 assemblage) suggesting that some people living at or visiting the site were beginning to expend energy and/or wealth acquiring greater quantities of material from those higher quality but more distant grindingstone sources. Such increases may represent another aspect of the socio-economic development that is evident during this incipient-urban or Early Harappa phase (Kenoyer and Meadow 1999).

The percentage of Kirana Hills stone used by Harappans occupying the two main mounds during this period does not seem to have not differed greatly (68.9% for AB vs. 60.6 % for E). Residents of Mound E seem to have used much more Pab sandstone their

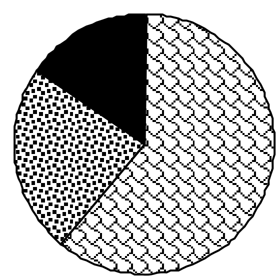
Figure 5.10: Grindingstone source utilization by mound – **Period 2**
(percentage calculated by *total weight* of each type)

Delhi quartzite | Gray Sandstone | Kirana Hills stone | Pab sandstone | Unknown provenience

Mound AB	amount	weight (g)	percentage
Delhi quartzite	4	354.2	1.33%
Gray sandstone	2	253.4	0.95%
Kirana Hills stone	82	18290	68.89%
Pab sandstone	7	1204.9	4.54%
Unknown	26	6447.2	24.28%
total	121	26550	100.00%



Mound E	amount	weight (g)	percentage
Delhi quartzite	1	43.1	0.40%
Gray sandstone	0	0	0.00%
Kirana Hills stone	65	6529	60.63%
Pab sandstone	8	2509.1	23.30%
Unknown	13	1686.7	15.66%
total	87	10768	100%



counterparts on AB (23.3% for E vs. only 4.4 % for AB). People living on AB, however made of some of the difference by utilizing Delhi quartzite and gray sandstone (2.2% combined) while only 1 small fragment of Delhi quartzite and no gray sandstone grindingstones at all have been recovered thus far from Period 2 level on Mound E.

In general, it seems that although all residents of Harappa still relied on the closest sources for the majority of their grindingstone requirements during Period 2, they were beginning to acquire a markedly larger portion (nearly one-quarter of the overall total in the

case of Mound E) of material from more distant sources. The fact people residing on Mound E used over 80% more Pab sandstone than people on AB could *perhaps* indicate that the former group had stronger economic and/or social ties to the region west of Harappa at this time.

Harappa Phase – Period 3A (2600 to 2450 BC)

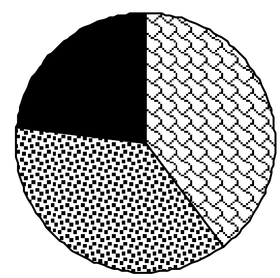
Fully urban lifeways at Harappa had emerged by Period 3A, the first of three sub-periods of the Harappa Phase. Unlike other some other Indus sites where there are reported to be sharp demarcations between the Early Harappan and Harappan occupations – such as at Kot Diji (a site-wide episode of burning – Khan 1965) or Ghandi Umar Khan (a 50 cm sterile layer – Ihsan Ali 2004 *personal communication*), the transition between the two periods at Harappa itself is one of "gradual transformation" (Meadow and Kenoyer 2001: 25). Approximately 20 grindingstones came from levels deposited during the late Period 2 to early 3A transition. The context of each of those artifacts was judged individually and, for analytical purposes, was assigned to either Period 2 or 3A. Even though the majority were placed into the Period 3A group, the number of querns and mullers from this period totals only 45 artifacts, which are more or less even split between excavated 3A levels on Mounds AB and E (Figure 5.11). With the exception of the combined Periods of 4 and 5, this assemblage represents the smallest sample we have for any of the periods under consideration. Even a handful of samples added to any one of the material categories could significantly alter the percentages presented here. I have raised the issue at this point because although the Period 1 grindingstone assemblage was nearly as small (n=58) as this one, the site at that time is thought to have been only been seven to ten hectares in size

(Kenoyer and Meadow 2000: 56). By Period 3A, however, Harappa was substantially larger. Thus, for this phase we are dealing with both a smaller sample and a bigger area. For these reasons, the data below for this period should be treated with due caution and considered tentative.

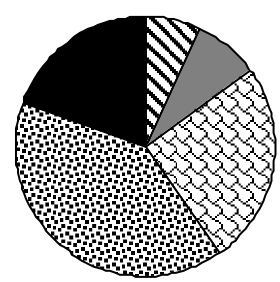
Figure 5.11: Grindingstone source utilization by mound – **Period 3A**
(percentage calculated by *total weight* of each type)

Delhi quartzite · Gray Sandstone · Kirana Hills stone · Pab sandstone · Unknown provenience

Mound AB	amount	weight (g)	percentage
Delhi quartzite	0	0	0.0%
Gray sandstone	0	0	0.0%
Kirana Hills stone	6	3123.2	39.7%
Pab sandstone	6	2928	37.2%
Unknown	9	1823.4	23.2%
total	21	7875	100%



Mound E	amount	weight (g)	percentage
Delhi quartzite	2	313.4	6.9%
Gray sandstone	2	374	8.2%
Kirana Hills stone	7	1152	25.2%
Pab sandstone	6	1840.3	40.3%
Unknown	7	892.2	19.5%
total	24	4572	100%



In Period 3A the use of Kirana Hills stone falls to around half of what it was during the Kot Diji Phase. This material still, however, makes up fully one-third (34.3%) of the material used as grindingstone by Harappans at that time. Conversely, the utilization of Pab

sandstone sees a four-fold increase over the preceding period (rising to 40.1%) making it, for the first time, the most common type of grindingstone used at Harappa. The portion of Delhi quartzite in the assemblage rises slightly (to 2.5%) while gray sandstone use drops a bit (to 3.0%).

To date grindingstones have been recovered only from Period 3A levels on mounds AB and E. When assemblage compositions on those two habitation areas are compared it is evident that for Pab sandstone there is hardly any disparity in material use between them (40.3% for E vs. only 37.2% for AB). It does appear that Harappans residing on Mound AB tended to use somewhat more (39.7%) Kirana Hills stone than did those dwelling on Mound E (25.2%). People on Mound E, however, made up the difference by utilizing Delhi quartzite and gray sandstone (15.1% combined) while neither of those materials have been recovered thus far from Period 3A level on Mound AB.

In summary, despite the fact that during this initial period of the fully urban phase the percentage of querns and mullers made from Kirana Hills stone falls considerably, these closest rock outcrops to Harappa remained significant sources for grindingstone material. The emphasis, however, had evidently begun to shift toward the acquisition-consumption of higher quality Pab sandstone from more distant sources in the Sulaiman Range. Differences in source utilization between habitational areas at Harappa do not seem to be pronounced during this period. Once again, because of the small sample of grindingstones from Period 3A in combination with the larger size of Harappa at that time levels, these conclusions should be considered tentative.

Harappa Phase – Period 3B (2450 to 2200 BC)

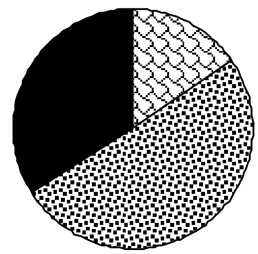
Approximately three times as many grindingstone samples (n=128) have been recovered from stratified contexts in Period 3B (Figure 5.12) than from the preceding phase. However, with the addition of querns and mullers recovered from Period 3B levels on mounds F and ET, a greater spatial area is now under consideration. Therefore a degree of caution is once again advised, especially for data from mounds AB and F where only 11 and 7 (respectively) grindingstone artifacts have been recovered for this time period.

Period 3B, which was a time of urban renewal for some Harappans – notably those residing on Mound E (Kenoyer 1992a: 6), sees some rather significant shifts in grindingstone source-type utilization at Harappa. Kirana Hills stone, the dominant material type for the first two periods at Harappa, now accounts for only 2.2% of the overall grindingstone assemblage. It appears instead that Harappans are acquiring nearly 70% of their querns and mullers in the form of Pab sandstone from the Sulaiman Range. Small increases in the use of Delhi quartzite and gray sandstone are once again seen during this period. When assemblage compositions between mounds E and ET (the two habitation areas from which the most samples were recovered) are compared we see that the differences between them are generally slight. Pab sandstone was by far the most-used material for grindingstone on both mounds (76.2% for E vs. only 71.0% for ET) and the three remaining identifiable types collectively account for approximately 10 to 15 percent of the assemblages in both areas. Such similar patterns suggest close ties between the two areas. Although evidence of occupation east of Mound E in the area now defined as Mound ET extends back to the Kot Diji Phase (Meadow and Kenoyer 1997: 140), grindingstones

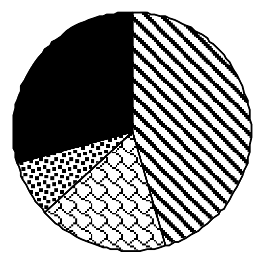
Figure 5.12: Grindingstone source utilization by mound – **Period 3B**
(percentage calculated by *total weight* of each type)

Delhi quartzite · Gray Sandstone · Kirana Hills stone · Pab sandstone · Unknown provenience

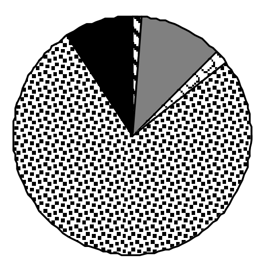
Mound F	amount	weight (g)	percentage
Delhi quartzite	0	0	0.00%
Gray sandstone	0	0	0.00%
Kirana Hills stone	1	211.5	15.31%
Pab sandstone	3	703.1	50.88%
Unknown	3	467.3	33.82%
total	7	1382	100%



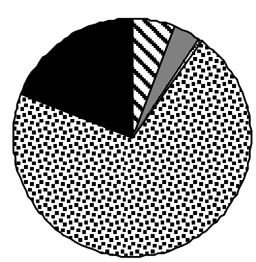
Mound AB	amount	weight (g)	percentage
Delhi quartzite	2	1652.3	45.65%
Gray sandstone	0	0	0.00%
Kirana Hills stone	4	628.9	17.38%
Pab sandstone	1	285.3	7.88%
Unknown	4	1052.8	29.09%
total	11	3619	100%



Mound E	amount	weight (g)	percentage
Delhi quartzite	2	201.1	1.29%
Gray sandstone	3	1740.3	11.16%
Kirana Hills stone	5	330.3	2.12%
Pab sandstone	29	11891.8	76.25%
Unknown	13	1431.6	9.18%
total	52	15595	100%



Mound ET	amount	weight (g)	percentage
Delhi quartzite	5	2206.6	5.86%
Gray sandstone	3	1381.9	3.67%
Kirana Hills stone	3	140.9	0.37%
Pab sandstone	37	26757.6	71.02%
Unknown	7	7189.7	19.08%
total	55	37677	100%



have only been recovered in 3B and later levels on that mound. By that time, Mound ET was encompassed by a perimeter wall (built in late Period 3A or early Period 3B), which extended directly from the city walls of Mound E (ibid.: 143-144) and joined the two habitation areas in manner suggesting that expansion of, or annexation by, the larger mound took place. If during Period 3B the residents of Mound E exerted a degree of control regarding what raw materials were used by people living and working on Mound ET or if the residents of both mounds were members of the same social-political group, then the closely related source-type use patterns seen for the two areas are understandable.

On mounds AB and F the assemblage compositions appear quite different than those of mounds E and ET. When compared to the overall percentage, Kirana Hills stone accounts for a minor but still significant portion of the grindingstones on both mounds (15.3% for F vs. only 17.3% for AB). Delhi quartzite is the most (45.6%) utilized grindingstone on AB during Period 3B while Pab sandstone use falls far below site-wise average at only 7.88%. On Mound F only two of the identifiable types of querns and mullers appear to have been used. Pab sandstone makes up just over half of the assemblage while Kirana Hills stone (mentioned above) accounts for a smaller portion.

In summarizing this period it is worth again emphasizing that the grindingstone assemblages from Period 3B levels on Mounds AB and F are extremely small. Even so, the differences in assemblage source-type composition between mound group E-ET and AB (and to a lesser degree Mound F) may actually have some basis in the reality of grindingstone acquisition behavior during this sub-phase. As mentioned above, Period 3B was a time of rebuilding and renewal on Mound E and perhaps ET. It is conceivable then

that at this time residents in these areas of the site were generally more affluent than their fellow Harappans residing on mounds AB and F and so could afford to expend more wealth obtaining high quality Pab sandstone. On the other hand, it may indicate that the people of mounds E and ET had stronger social-economic times with the groups in the Sulaiman region than did those dwelling on the other mounds – a situation similar to the one that *perhaps* also existed for Mound E during the Kot Diji Phase. Or (quite possibly) the very small sample sizes for mounds AB and F may have resulted in an inaccurate representation of the true source-type composition for those areas. Whatever the case may be, overall this period does see the continuation of trends that had been developing since the early phases – namely, increasingly steeper declines in the use of Kirana Hills stone over time, progressively greater use Pab sandstone and a slow but steady increase overall of Delhi quartzite utilization.

Harappa Phase – Period 3C (2200 to 1900 BC) and surface/disturbed context finds

Harappa's grindingstone assemblage from Period 3C is the most robust of the entire sequence, consisting of over 1000 artifacts. Examples have been recovered in nearly every trench across the site in which Period 3C deposits have been exposed, which is to say – nearly every trench across the site. Thus, appraisals of grindingstone source-type usage between habitation areas made for Period 3C are the most statistically secure and spatially representative of any chronological phase.

Looking at the overall source-type use pattern for Period 3C, we see that Pab sandstone is again the most utilized material for grindingstone at Harappa, although its percentage in the assemblage decreases to around 44% from its high of nearly 70% during

the preceding period. Some of that decrease may be due to concurrent increases in the utilization of Delhi quartzite, which jumps markedly to 21.5% of the total, and gray sandstone, which sees its highest percentage (9.5%) in the entire chronological sequence. In general, Kirana Hills stone was infrequently (3%) used for grinding purposes during Period 3C.

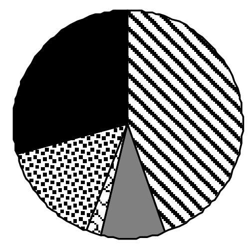
Turning now to source-type usage between Harappa's mounds during Period 3C (Figure 5.13), we once again observe that the grindingstone use patterns for mounds E and ET are remarkably similar. Pab sandstone was the most utilized material for querns and mullers on E and ET– ranging from 52% to 57% of the assemblages. Delhi quartzite was used approximately 20% of the time, gray sandstone 8% and Kirana Hills stone less than 3% on both mounds. The continuation from Period 3B of roughly parallel assemblage compositions provides additional evidence that may indicate that factors determining grindingstone usage (be they economic or social-political) were the same for residents on both mounds E and ET.

Over on mounds AB and F, we again see in this period that the patterns of use in those areas were quite different that those on E-ET. On Mound F, Delhi quartzite made up around half (44.7%) of the grindingstones used (twice as much as in any other area), Pab sandstone use was approximately one-third (15%) of the site average of 43.8% and the utilization of gray sandstone and Kirana Hills stone was roughly same as the site averages for those materials. On Mound AB, Pab sandstone made up one-third (33.1%) of the assemblage while another one-third were more or less evenly divided between the other three identifiable grindingstone types. Also in contrast to mounds E-ET, the assemblage

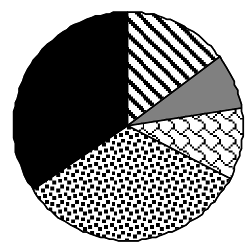
Figure 5.13: Grindingstone source utilization by mound – **Period 3C**
(percentage calculated by *total weight* of each type)

Delhi quartzite — Gray Sandstone — Kirana Hills stone — Pab sandstone — Unknown provenience

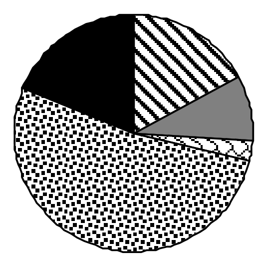
Mound F	amount	weight (g)	percentage
Delhi quartzite	49	21120	44.7%
Gray sandstone	10	4347	9.2%
Kirana Hills stone	6	946	2.0%
Pab sandstone	17	7090	15.0%
Unknown	54	13742	29.1%
total	136	47245	100%



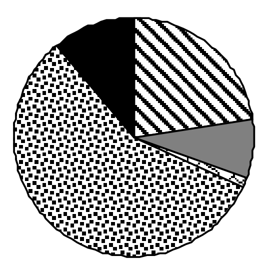
Mound AB	amount	weight (g)	percentage
Delhi quartzite	21	6357	14.78%
Gray sandstone	10	3383	7.86%
Kirana Hills stone	8	4272	9.93%
Pab sandstone	24	14261	33.14%
Unknown	34	14932	34.71%
total	97	43205	100%



Mound E	amount	weight (g)	percentage
Delhi quartzite	96	25180	17.35%
Gray sandstone	22	12853	8.86%
Kirana Hills stone	10	3911	2.69%
Pab sandstone	159	75906	52.31%
Unknown	117	27268	18.79%
total	404	145117	100%



Mound ET	amount	weight (g)	percentage
Delhi quartzite	73	16202	22.55%
Gray sandstone	20	5824	8.10%
Kirana Hills stone	11	947	1.32%
Pab sandstone	85	40976	57.02%
Unknown	51	7914	11.01%
total	240	71862	100%



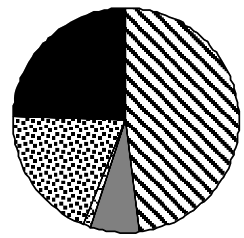
compositions on both mounds AB and F for Period 3C differ greatly from than the ones for those same areas during the preceding period. This *perhaps* indicates that the factors (local and/or external to Harappa) influencing resource acquisition for residents of those mounds were somehow in flux between periods 3B and 3C. However, I would point out yet again that the perceived diachronic differences could be misleading due to the small sample sizes for Periods 3B assemblages on AB and F.

It useful at this point to examine the mound by mound grindingstone assemblage composition data for artifacts recovered during surface surveys and from disturbed contexts such as brick robber trenches (Figure 5.14). A comparison of the pie-charts in figures 5.13 and 5.14 shows that the patterns of the surface-disturbed assemblages closely mirror, in most cases, those of Period 3C assemblages from their respective mounds. I suggest here that those patterns help substantiate the grindingstone usage patterns that have been defined for Harappa's individual mounds during Period 3C. It is of course true that querns and mullers found in such non-secure contexts could be from any chronological phase (even historic or modern). However, the brick robbing of the mid-19th century effectively removed nearly all of the upper levels of the site resulting in the exposure of mostly Period 3C deposits across Harappa's surface. It is probable that many (perhaps even a large majority) of querns and mullers recovered from the present-day surface of the site (or in brick robber trench fill that derived from the surface or higher levels) come from that occupational phase. In addition, every meter of the site's surface has been surveyed by the HARP at one time or another resulting in a substantial collection of grindingstones representing each of the major mounds (n = 917 total). Although it's true that unstratified or

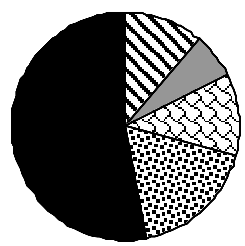
Figure 5.14: Grindingstone source utilization by mound –
Surface and disturbed contexts
(percentage calculated by *total weight* of each type)

Delhi quartzite | Gray Sandstone | Kirana Hills stone | Pab sandstone | Unknown provenience

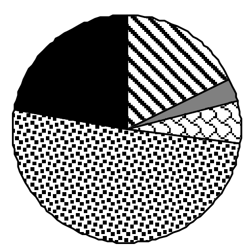
Mound F	amount	weight (g)	percentage
Delhi quartzite	25	23319	48.12%
Gray sandstone	6	3387	6.99%
Kirana Hills stone	4	485	1.00%
Pab sandstone	17	9464	19.53%
Unknown	34	11807	24.36%
total	86	48462	100%



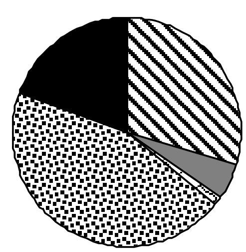
Mound AB	amount	weight (g)	percentage
Delhi quartzite	26	5532	10.99%
Gray sandstone	9	3300	6.55%
Kirana Hills stone	31	5913	11.74%
Pab sandstone	31	9026	17.92%
Unknown	90	26589	52.80%
total	187	50360	100%



Mound E	amount	weight (g)	percentage
Delhi quartzite	116	24177	17.88%
Gray sandstone	14	4218	3.12%
Kirana Hills stone	21	7975	5.90%
Pab sandstone	197	68947	51.00%
Unknown	133	29883	22.10%
total	481	135201	100%



Mound ET	amount	weight (g)	percentage
Delhi quartzite	47	12840	29.84%
Gray sandstone	12	2089	4.85%
Kirana Hills stone	2	508	1.18%
Pab sandstone	61	19248	44.73%
Unknown	41	8347	19.40%
total	163	43032	100%



redeposited artifacts such as these may have been moved far from their original points of deposition, it is highly unlikely that a substantial number of them (if any) came from a mound other than the one on which they were found. In other words, a quern recovered from the surface of Mound AB was almost certainly used by the former residents of Mound AB. For these reasons I would argue that, as long as its potential limitations are recognized, the similar source-type composition of the surface-disturbed assemblage provides a good line of supporting evidence for the patterns of grindingstone use at Harappa during Period 3C and later phases.

In summary, although Pab sandstone remained the most commonly used material for querns and mullers at the Harappa during Period 3C, Delhi quartzite was being brought to the site in much higher quantities than before, suggesting that long-distance trade to regions east of the site was intensifying during this period. Residents of Mound F appear to be the ones most actively involved in these eastern grindingstone acquisition networks as they consumed twice as much as the site-wise average for Delhi quartzite. Gray sandstone and, in particular, Kirana Hills stone, were used in only small amounts overall. However, even though the assemblage composition on Mound AB is fairly mixed, people living there did use three times the site-wise average for Kirana Hills stone. In fact, residents of AB had been the highest users of Kirana Hills stone for every phase going back to Period 2. Those who lived on mounds E and ET continued to exhibit patterns of grindingstone source-type usage similar to each other. Although still relying mostly on Pab sandstone, they too were using an increasingly greater amount of Delhi quartzite.

Transitional and Late Harappa Phase – Periods 4 & 5 (ca. 1900 to <1300 BC)

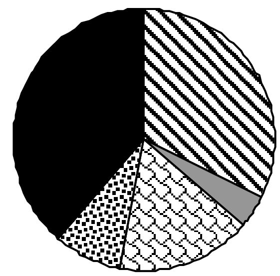
Due to the fact that intact post-Period 3C deposits are rare at Harappa, the total number of querns and mullers recovered from the Harappa to Late Harappa Transitional Phase (Period 4) and Late Harappa Phase (Period 5) is small (n=20). Artifacts from these periods are therefore considered as a single assemblage. Also, although there is evidence that Late Harappa occupations existed on Mounds F and E-ET, all of the grindingstones from those phases come from a single trench (Tr. 38) on the north side of Mound AB. It should be kept in mind, then, that the usage pattern for this small part of Mound AB may not be at all representative of what was occurring elsewhere on the site, especially since this was often the case in other periods (notably 3B and 3C).

Despite the apparent cessation of important long-distance interaction networks with Sindh and Gujarat during the later periods at Harappa, several lines of evidence (demographic, paleoethnobotanical, technological) suggests that activity and innovation continued at Harappa itself (Kenoyer 2005b). Interesting new patterns also appear to have been taking place during these late occupational phases in terms of grindingstone acquisition (Figure 5.15). Both Delhi quartzite (32.2%) and "unknown" grindingstone types (38.5.7%) reach their highest percentages for any chronological phase. Delhi quartzite was, for the first time, more frequently used than Pab sandstone, which now accounts for fewer than 10% of the artifacts in the assemblage. In addition, Kirana Hills stone was used twice as often as Pab sandstone while utilization of gray sandstone dropped by half over Period 3C.

Figure 5.15: Grindingstone source utilization on Mound AB – **Periods 4/5**
(percentage calculated by *total weight* of each type)

Delhi quartzite — Gray Sandstone — Kirana Hills stone — Pab sandstone — Unknown provenience

Mound AB	amount	weight (g)	percentage
Delhi quartzite	7	988.5	32.16%
Gray sandstone	2	133.2	4.33%
Kirana Hills stone	2	512	16.66%
Pab sandstone	2	257.1	8.37%
Unknown	7	1182.6	38.48%
total	20	3073	100%



The changes in material source-type usage seen on Mound AB may reflect the general demographic shift of Harappan peoples toward the eastern Punjab and the western Gangetic region that occurred during the Late Harappan Periods (Possehl 1997b). As the emphasis on trade and interaction shifted eastward, Delhi quartzite source would have been even more accessible through interaction with the Late Harappans of Haryana. Access to new sources of grindingstone from around the Gangetic region could account for the increase in “unknown” types. The dramatic drop in Pab sandstone use may indicate that contacts with areas to the west of Harappa had decreased in intensity or at least that the nature of the interaction networks shifted away from the supply of bulk goods. A slightly greater reliance on closer sources for utilization materials during this period is suggested by the small increase in the presence of Kirana Hills stone in the assemblage.

Discussion – Patterns of grindingstone acquisition and discard at Harappa

Residents of Harappa acquired the majority of the stone that they used for processing cereals and other grinding purposes from one of four regions. From the Sulaiman Mountains they acquired Pab sandstone and, perhaps, some gray (Mughal Kot) sandstone. The type of Delhi quartzite Harappans used seems to have been brought from a fairly restricted area (Kaliana Hills) of southern Haryana. Many of the gray sandstone querns and mullers found at the site probably were acquired from the Lower Himalayas or Siwaliks foothills, which stretched from Jammu to Uttaranchal. Finally, it appears that two different types of stone from the (relatively) nearby Kirana Hills were used. The presence of each of these types of stone at Harappa provides unambiguous evidence that some form of interaction (either direct or indirect) existed between the site and the regions from which they originated. In forthcoming chapters, I demonstrate that numerous varieties of stone and metal found at Harappa came from the Salt Range or regions beyond it. Somewhat conspicuous in its absence, then, is stone from those mountains such as Khewra sandstone. It would almost certainly be identifiable in the site's grindingstone assemblage if it were present. In any case, this geologic provenience study of querns and mullers demonstrates that residents of Harappa of all phases participated in exchange networks for utilitarian goods that extended across an area of no less than 600 km from west to east.

Examples of all four of the identifiable grindingstone types are present in each phase at Harappa. The proportions of those types that make up each chronological sub-assemblage, however, vary significantly from phase to phase. The most striking change in grindingstone source-type usage is the shift in emphasis over time toward the acquisition of

stone from sources between 225 and 400 km away from the site. For approximately 1000 years following the initial settlement of Harappa, the large majority (≈ 85%) of mullers and querns were brought to the site from the closest possible sources in the Kirana Hills, which were only 120 km away. A trend toward the acquisition of stone from the more distant sources begins in the proto-urban phase (Period 2) and culminates in the middle of the urban phase (Period 3B) when only 2% of grindingstones used there came from the Kirana Hills region.

Why, over time, would residents of Harappa increasingly acquire their grindingstones from comparatively distant sources when much closer ones were at hand? Doing so would surely have required them to expend a greater amount of energy and/or wealth. The loss or establishment of interaction networks to source regions does not provide a satisfactory answer to the question. As discussed above, Early Harappan period sites are found in the areas where the more distant grindingstone sources are located (at the base of the Sulaiman Range and in southern Haryana) and Harappan period settlements are found in the vicinity of the Kirana Hills. I would argue that the answer probably has to do with factors relating to qualities of material from different sources in combination with innovations that accompanied the emergence of urban lifeways in the greater Indus region.

Because of their homogeneity, grain size and toughness, Pab Sandstone, Kaliana-type Delhi quartzite and fine gray sandstone are, as compared to the stone available in the Kirana Hills, superior materials for grinding purposes. As just noted, impediments to acquiring those higher quality material types during the Ravi and Kot Diji phases at Harappa probably did not stem from a lack of access to the regions in which they occurred.

It is more likely that transportation technologies and infrastructure in the upper Indus Basin during the Early Harappan Phase had not yet developed to the point where moving heavy stone implements overland in large quantities was cost-effective. Transporting heavy loads of stone from the Kirana Hills to Harappa and other sites in the central Punjab could have been easily accomplished by moving them a large portion of the way via watercraft downstream on the southeasterly flowing rivers of the region. The most direct routes from grindingstone sources in the Sulaiman Range and southern Haryana, on the other hand, run mostly perpendicular to those waterways. The transportation of Pab sandstone or Kaliana-type Delhi quartzite to Harappa would have, therefore, had to have taken place mainly via overland routes and on watercraft traveling upstream. As a result, the best quality querns and mullers would have been comparatively more costly to acquire in terms of wealth and/or energy expended.

Transporting heavy loads of stone by land would have been most effectively undertaken using a bullock-pulled two-wheeled cart – an innovation the origins of which are documented at Harappa and other Indus Civilization sites during the fourth and third millennia BC (Kenoyer 2004). Although there is limited evidence of its existence during the Ravi Phase at Harappa, use of the bullock cart increases during the Kot Diji Phase, which incidentally is also the time we see the initial small increase in Pab sandstone in the grindingstone assemblage. Evidence for widespread use of carts across the Greater Indus region and beyond is seen during the Harappa Phase (ibid.). It is during that time, of course, that grindingstones transported from relatively distant sources are the most utilized at Harappa.

Wheeled vehicles traveling across the plains of the Indus Basin would have required some kind of infrastructure in the form of roads or, at the very least, a clear trail. Although no such roadways from this period have yet been discovered, the well-planned streets and broad avenues of Indus towns and cities allow us to reasonably assume that some form of maintained route probably existed in the countryside between Indus settlements. So, with the development of new transportation technologies (documented) and infrastructure (inferred) it became easier to supply Harappa with grindingstones from multiple sources around the upper Indus Basin. As a wider range of materials for querns and mullers became easier to get many residents of the site chose to utilize the stone of better quality.

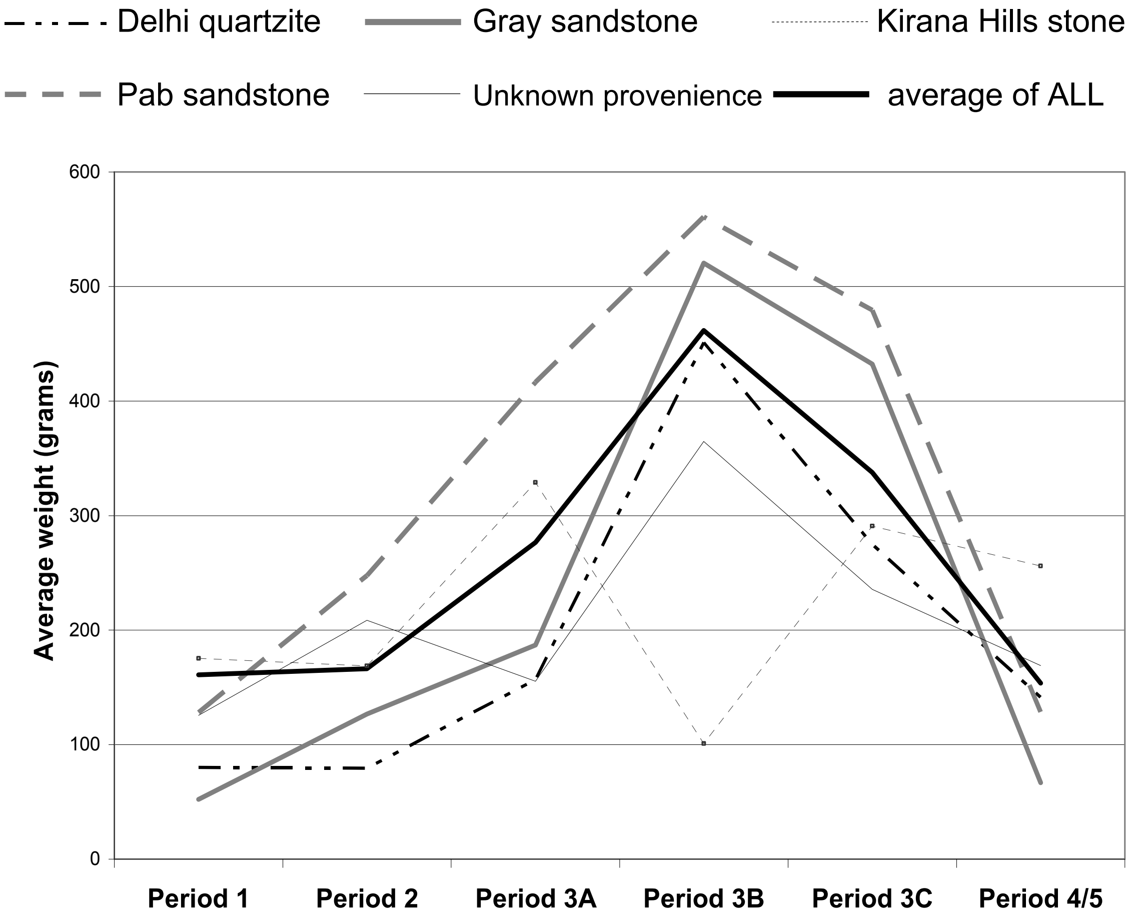
The shift toward more distant grindingstone sources could also reflect the general economic prosperity of urban phase Harappans. Residents of an increasingly urbanized settlement, in contrast to their village-dwelling ancestors, might have had comparatively more accumulated wealth to expend on the acquisition and transport of higher quality utilitarian necessities. Without the benefit of readable texts it is difficult to know precisely what value Harappans may have placed on any material. However, it may be instructive to consider changes in the average weight of the grindingstone artifacts during different periods. Less than 5% of the querns and mullers from Harappa have been found in a complete or nearly complete state. It appears that Harappans used these implements until they broke and then continued to re-use the pieces until at some point they were judged to be too small to be effective. By looking at the average weights for grindingstone artifacts it is possible to get an idea of how small that point was from period to period and from that, a

relative sense of how willing Harappan were to discard grindingstone material at different points in time.

Figure 5.16 is a line graph plotting the average weights of individual material types through time at Harappa. Although average weights vary from type to type, most follow a similar trend. This trend is clearly evident when the average weights of all types in a single chronological assemblage are calculated and plotted period by period (bold black line). The general trend is as follows: During both periods 1 and 2 the average weight of discarded grindingstones hovered around 160 g. In the early part of the urban phase (Period 3A) the fragments thrown away were over 100 grams heavier on average than in the previous phases. By Period 3B the average quern or muller discarded by a resident of Harappa was nearly half a kilogram in weight. In the later part of the Harappa Phase (Period 3C) fragments of grindingstones deemed unusable were somewhat smaller (average 365 g) than before. Finally, it appears that Late Harappans (Period 4/5) tended to discard used grindingstones of a weight (153.6 g) that was slightly lower on average than in periods 1 and 2.

How valid are these trends base on average weight? It could be argued that there were factors affecting the average weights of grindingstone artifact assemblages other than, or in addition to, the point at which Harappans of different phases were choosing to throw their querns and mullers away. Any number of post-depositional processes may have acted upon these implements. Also the properties of the different material types themselves may have affected their weights. I have argued that one of the reasons that Kirana Hills stone was of poorer quality and therefore less preferred over other types is because it is more

Figure 5.16: Average weights of grindingstones (whole and fragmentary) by period.



	Period 1	*n* =	Period 2	*n* =	Period 3A	*n* =	Period 3B	*n* =	Period 3C	*n* =	Period 4/5	*n* =
Delhi quartzite	80.2g	*1*	79.5 g	*5*	156.7g	*2*	451.1g	*9*	274.7g	*269*	141.2g	*7*
Gray SS	52.15g	*2*	126.7g	*2*	187g	*2*	520.4g	*6*	432.2g	*75*	66.6g	*2*
Kirana Hills stone	175.3g	*45*	168.8g	*147*	328.9g	*13*	100.9g	*13*	290.9g	*36*	256g	*2*
Pab SS	128g	*2*	247.6g	*15*	416.4g	*12*	560.8g	*72*	479.2g	*314*	128.5g	*2*
Unknown	125.4g	*8*	208.6g	*39*	155.4g	*16*	364.8g	*28*	235.5g	*322*	168.9g	*7*
Average of all types	160.9g	*58*	166.2g	*208*	276.6g	*45*	461.6g	*128*	337.7g	*1016*	153.6g	*20*

friable and, thus, more apt to break during use. Should we expect to find many more small pieces of this type as compared to the others? Perhaps not, because it is only in Period 3B that Kirana Hills stone has the smallest average weight of all types. Nor does it appear that varying assemblage sizes from phase to phase is a factor. That is, the trend evident in Figure 5.15 appears to be independent of total number of samples considered in each phase. I would argue these average weights are reasonably good indicators of how the point at which Harappans decided it was worth discarding (and presumably replacing) grindingstone changed from phase to phase. Pab sandstone and Kirana Hills stone both would have been discarded when they more or less reached the same weights. Higher quality Pab sandstone, however, would have lasted longer before reaching that point.

The overall trend evident in Figure 5.15 would make it appear that Early Harappans (periods 1 and 2) were more inclined than their urbanized counterparts in Period 3 to use and re-use broken grindingstone fragments until they were very small. This suggests that such stone was dearer to them than it was to urban phase Harappans. That is, it was probably less readily available and/or more costly to acquire. During Period 3 it seems Harappans were more apt to discard larger pieces of grindingstones despite the fact that the majority used at that time tended to be composed of higher quality materials from distant sources. This suggests that grindingstone during Period 3 generally was not as valuable as it was during Periods 1 and 2 and/or that a reliable supply of comparatively inexpensive material was available to replace broken implements. Interestingly, it is in Period 3B that both the highest proportions of stone from sources over 200 km distant are found in Harappa’s grindingstone assemblage and that the heaviest fragments are being discarded.

It could be said that during Period 3B, more than in any other period, high quality querns and mullers were plentiful (there were a higher proportion of them) and cheap (they were more readily discarded). The slight drop in the average weight of grindingstones discarded by Period 3C Harappans may reflect a situation where the amounts of new grindingstone being brought to Harappa through regional trade networks was declining. A deterioration of architectural quality and the maintenance of public thoroughfares suggest that civic authority at Harappa was beginning to wane during that period (Kenoyer 1992a: 6). The steep decline in the average weight of discarded grindingstones that is evident in the Late Harappa Period (4/5) may then indicate that some of those networks had further or failed entirely.

Turning now to intra-site variation in grindingstone source usage, the only phases for which it is possible to compare patterns between two or more habitation areas at Harappa are periods 2 through 3C. In several instances the assemblages recovered from particular mounds are very small (n < 25). This may have resulted in unrepresentative or biased source-type usage patterns. However, even when the possible shortcomings of certain aspects of the dataset are taken into account, there appears to have been some genine synchronic variation among the habitation areas at Harappa.

Looking first at intra-site similarities we see that all four of the identifiable grindingstones types were used to some degree or another by residents of each of Harappa's habitation areas. Occasionally grindingstone types are missing from some mound assemblages during certain periods but that is probably due, in large part, to problems related to small sample size rather than absence of a material type. It would

seem safe to say that all Harappans, regardless of what part of the city they lived in, would have had access to any of the four material types if they wished to acquire them.

Residents of Mounds E and ET left behind more or less parallel patterns of grindingstone source-type usage during both Period 3B and Period 3C. The surface and disturbed context assemblages from the two mounds were also alike in composition. This indicates that people living in both areas had very similar needs, preferences and/or opportunities when it came to choosing grindingstone material. Mound ET has been described as a "suburb" of Mound E (Kenoyer 1998: 55) that was eventually incorporated into it around Period 3B (Meadow and Kenoyer 1997: 140). These findings provide evidence that could be used to support an argument suggesting that residents of the two habitation areas were probably part of the same socio-political entity.

When looking at differences among habitation areas at Harappa we see that residents of Mound E (and eventually E-ET) always seemed to have been the heaviest consumers of Pab sandstone. Only in Period 2 did people of Mound AB use roughly the same amount of that material type. There are several possible explanations for this emphasis on Pab sandstone on mounds E-ET. One is that the peoples living there had the strongest economic and/or social ties to the trans-Indus regions adjacent to the Sulaiman Mountains such as Derajat and the Gomal Plain. It might also be the case that, of all the groups at Harappa, those on E-ET could best afford to expend wealth or energy acquiring high quality Pab sandstone. Or, perhaps, residents of the two joined mounds were engaging (at least more so than Harappans in other parts of the city) in types of craft production or other activities where Pab sandstone was required or particularly well-suited.

Overall, Harappans living and working on the other mounds used significantly less Pab sandstone – approximately one-third on Mound AB and two-thirds less on Mound F in Period 3C. Residents of Mound AB always seemed to have used an above average amount of Kirana Hills stone, even during periods 3B and 3C when that type was least utilized overall in the city. This may indicate that Harappans dwelling in that particular area, which was one of the oldest parts of the city, had the closest "local ties," as it were, to peoples in the northern part of the Punjab Plain. On the other hand, they might have had slightly less wealth than their contemporaries on other mounds to expend on higher quality types of grindingstone. Or maybe they simply did not engage heavily in activities that required grindingstones with the unique qualities of Pab sandstone.

On Mound F during Period 3C, which is the one phase in that part of the site for which there is a reasonably large grindingstone assemblage to consider, we see that residents there used twice as much Delhi quartzite as anyone else in the city (Mound F's assemblage from surface and disturbed contexts more or less parallels this pattern). This may indicate that, of all Harappa's residents, those in this part of the site had the strongest trade relationships with peoples to the east of Harappa. I later present results from a provenience study of steatite artifacts (Chapter 7) that seem to support this interpretation.

Chapter conclusion

The heavy and unwieldy nature of grindingstones makes examining artifacts in this category especially useful for detecting changes in the ability of ancient peoples to acquire stone resources that were difficult to transport. The large-scale study presented in this chapter revealed that residents of Harappa shifted away from the use of poorer quality

grindingstone from the closest available sources during the pre and early urban phases towards the acquisition of higher quality stone from distant sources during the urban phase. I infer that this shift was, in part, due to a marked increase in the capability of Indus Civilization peoples to transport bulk stone goods over long-distances. It may also indicate that high-quality grindingstones had become less expensive during Period 3 and/or that site residents had comparatively more wealth to expend on their acquitision.

In Chapter 13, the results of this study and their implications are considered again in relation to the various other geologic provenience studies comprising this dissertation. In the next chapter, I examine the acquisition and use of chert at Harappa and other Indus Civilization settlements. Chert, like grindingstone, was a vital utilitarian material that was acquired by residents of Harappa in large quantities.

Chapter 6

Chert acquisition networks

Chapter 6 – Chert acquisition networks

Chapter introduction – The three main types of chert at Harappa

Indus Civilization peoples, although heavy consumers of copper and skilled producers of copper-alloy implements, still chose to utilize chert to manufacture many of the tools (blades, drills, scrapers, awls, etc.) that they used in their daily lives. At Harappa, tools composed of this opaque variety of microcrystalline silicate (or, more commonly, the debris from the manufacture of them) make up over one-third (37.21%) of the over 56,000 artifacts in the site's rock and mineral assemblage. Chert also seems to have been the preferred stone for making the distinctively Harappan-style cubical weights. Visual examinations of this material sub-assemblage at Harappa indicate that there are three main macroscopically distinct types of chert represented in it (to see a selection of these refer back to Figure 4.3 B). A *purplish-hued chert/chalcedony* and a *black-brown*-colored chert are the two most abundant types in levels dating to the site's earliest two occupational phases (Ravi and Kot Diji phases). Black-brown cherts occur throughout Balochistan (Aubry et al. 1988) and, prior to this study, material of this type found at Harappa was believed to have originated from that region (Meadow and Kenoyer 2001: 24). Artifacts made of a tan to gray-colored (*tan-gray*) chert that often has a distinctive banded pattern have been recovered from strata representing all periods at Harappa. This type appears to have been the only one used during the site's urban phase (Period 3). Tan-gray chert that is sometimes banded is also found at Indus Civilization settlements across the entire Greater Indus region (Ratnagar 2001b: 64) and is widely believed to have originated in the extensive Rohri Hills chert quarries of northern Sindh (Allchin and Allchin 1997: 172).

In this chapter, I present an account of my attempts to determine from which regional geologic sources each of the three main macroscopically distinct types of chert in Harappa's rock and mineral assemblage were most likely derived. For the purplish hued chert/chalcedony, this entailed only the evaluation of that type in relation to chert artifacts in other contemporaneous archaeological assemblages, information in the geologic literature and observations in the field. For the black-brown and tan-gray cherts, however, I was able to directly compare a small set of artifacts (Figure 6.1) from Harappa and the Harappan Period site of Nagwada in Gujarat to samples from potential sources using instrumental neutron activation analysis (INAA). I have provisionally concluded that the purplish hued chert/chalcedony probably comes from volcanic trap rock formations in regions to the north of Harappa. Black-brown chert artifacts from Harappa were almost certainly derived from sources in the Salt Range. Although most of the tan-gray chert artifacts from Harappa and other Harappan sites like Nagwada are probably indeed from the Rohri Hills of Sindh, there are indications that other sources also may have been used.

Figure 6.2 shows the locations of the four trenches at Harappa from which 24 of the 25 chert artifacts analyzed for this study using INAA came from. INAA-derived elemental data for the geologic and archaeological samples are listed in appendices 6.1 through 6.6. Appendix 6.7 lists the standardized (canonical) discriminant function coefficients for each of the figures (6.12, 6.17 A & B) in this chapter that were generated using canonical discriminant analysis (CDA). All regions, sites and chert sources discussed below are noted on figures 6.3, 6.8 A & B and 6.16. I begin with a few brief observations/remarks on the ubiquity of chert in the Greater Indus region and at Harappa.

Figure 6.1: Chert samples from Harappa (numbered) and Nagwada (NGW) analyzed for this study. Numbers = appendices 6.1 and 6.4 and below



Figure 6.2: Harappa chert sample locations and contexts.

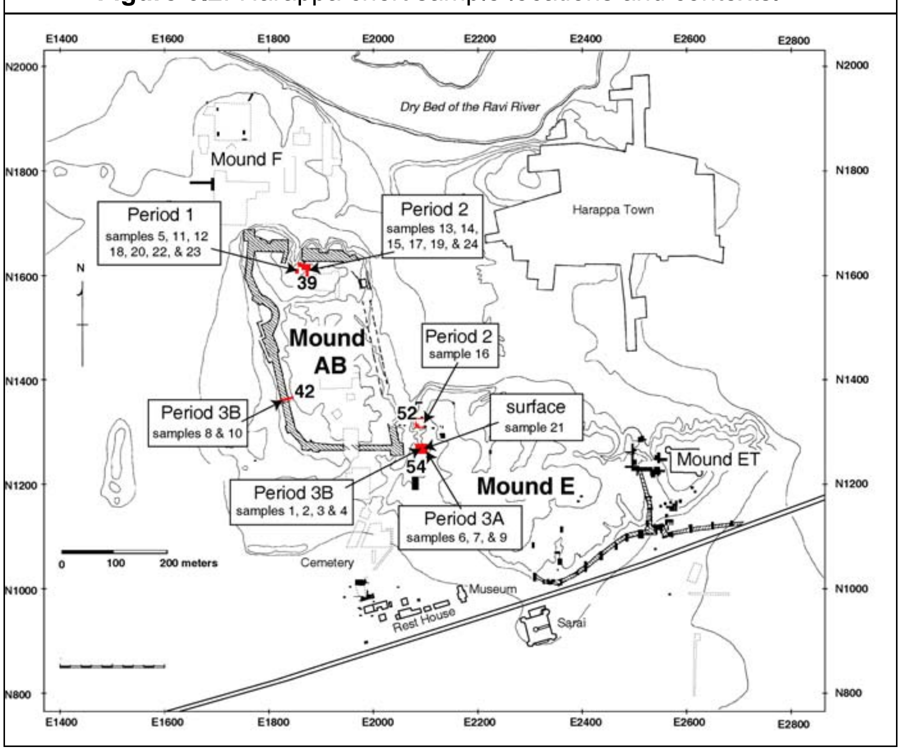


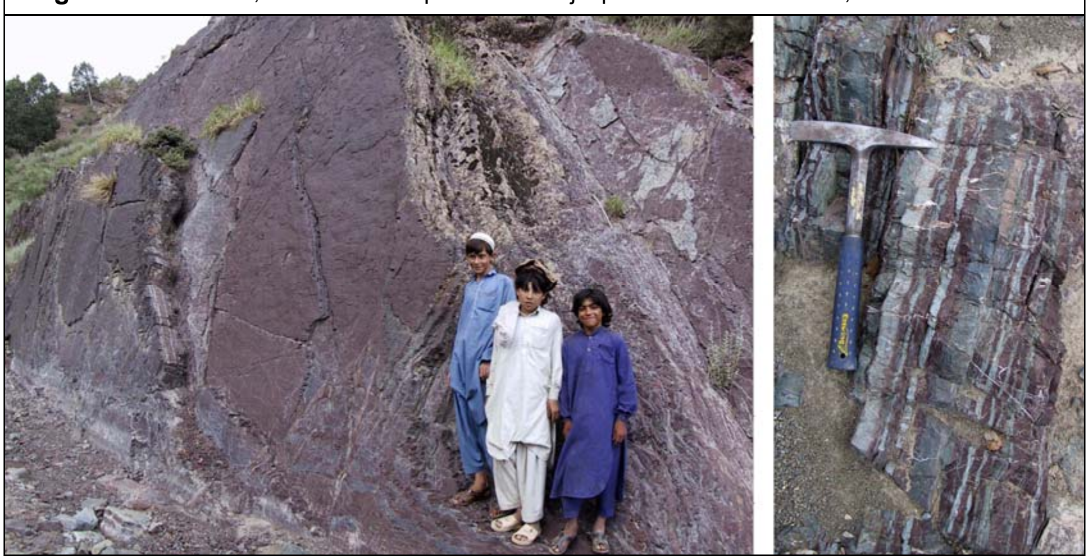
Figure 6.3: Regions, sites and chert sources discussed in this chapter



Chert in the Greater Indus region

Geologically speaking, chert is actually a rather ubiquitous material. It may form anywhere that "silica, in solution at low temperatures, can precipitate" (Luedtke 1992: 17). This includes sedimentary, metamorphic and volcanic rock formations (Blatt 1992). I have encountered it in one form or another within most of the regions that I have visited across northwestern South Asia. The ophiolite sequences of the Las Bela, Zhob and Waziristan regions literally contain small mountains composed entirely of massively bedded radiolarian chert/jasper (Figure 6.4). As their primary context host rocks erode, nodules and fragments of chert and other microcrystalline silicates may be transported and redeposited far from where they originally formed. I have collected bags of secondary context chert and jasper at places ranging from the Makran coast of Balochistan to the Baquka area of western Rajasthan. Still, although chert is widespread in the Greater Indus region, sources where good quality material (e.g. homogeneous unfractured stone for making long blades and other tools) may be acquired are relatively few in number.

Figure 6.4: Bedded, multi-colored ophiolitic chert/jasper formation at Barzai, North Waziristan



Chert at Harappa

Chert is also ubiquitous at Harappa. It is found in every part of the site and in every one of its chronological phases. Of the 20,967 chert artifacts tabulated by the HARP, 9,325 (44.5%) are from chronologically secure contexts. Figure 6.5 is a table showing how those are temporally distributed. All chert artifacts tabulated at Harappa were individually inspected by HARP team members and their technological attributes were painstakingly recorded. However, information on color, translucency and macroscopic patterning were not recorded in either the tabulation database or in the Harappa database. Time did not permit me to go back and record such attributes for every one of the chert artifacts from secure contexts but I was able to closely inspect most of the approximately 900 examples that date to periods 1 through 3A and Period 4/5. Only a cursory examination could be given to the remaining 8,400 or so chert artifacts from period 3B and 3C levels. Consequently, the relative abundances of the three main macroscopic types have not yet been calculated. The statements made in this chapter regarding their distributions are based solely upon my impressions from those examinations and my conversations with Prof. Mark Kenoyer, who has dealt with these artifacts for 22 years and knows where and when the different types are and are not found. Although much more work on this major material variety clearly needs to take place, I am confident that my inferences are reasonably accurate and will be borne out when quantitative data eventually become available.

Figure 6.5: Temporal distribution of the 9,324 chert artifacts at Harappa from secure contexts

Period 1	n = 625 *or* 6.70%
Period 2	n = 105 *or* 1.13%
Period 3A	n = 161 *or* 1.73%
Period 3B	n = 932 *or* 9.99%
Period 3C	n = 7472 *or* 80.13%
Period 4/5	n = 30 *or* 0.32%

Purple chert/chalcedony and other minor Early Harappan material sub-varieties

A wide range of microcrystalline silicates were used to make tools during the Early Harappan Period at Harappa (Figure 6.6 A & B). In Ravi Phase levels, all three main macroscopic types of chert are present along with a number of other material sub-varieties that include jaspers of different colors and even a few examples of *novaculite* – an opaque white microcrystalline silicate. My general impression is that tool material variety decreased slightly during the Kot Diji Phase. Only the three main chert types seem to be present in those levels. Jasper was still being used then but not to make tools.

Figure 6.6: Highly varied Ravi Phase cherts, chert/chalcedonies and other microcrystalline silicates.



Prominent in the lithic assemblages of the Early Harappan Period (especially during the Ravi Phase) is a type of *purple-hued chert/chalcedony*. This type tends to be quite variable in itself. Some examples are a completely opaque dark purple while others have a semi-translucent (thus the use of the combined term *chert/chalcedony*) light purple appearance with a "smoky" interior banding (the Ravi Phase blade seen in Figure 6.6 B *left*

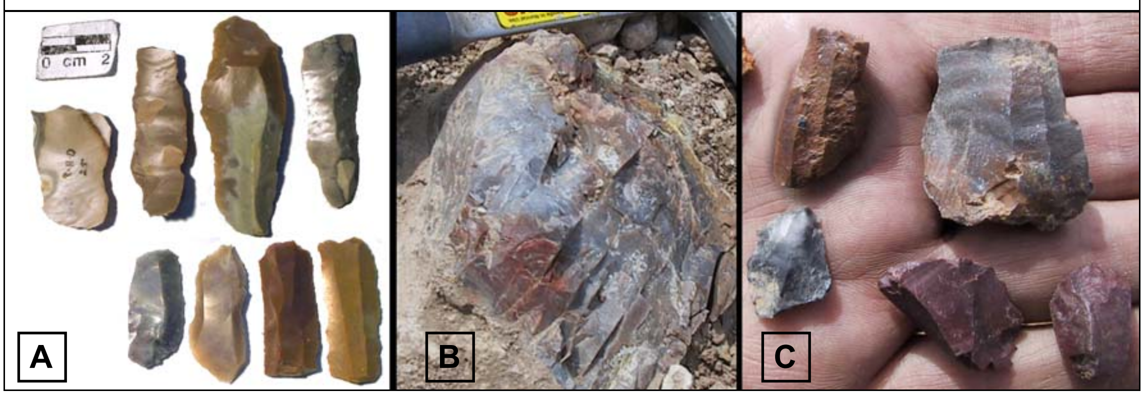
is a good example of the latter). It is very possible that there are actually two or more geologically distinct materials represented by this single macroscopic "type." It is also possible that the purple-hue is due to the chert/chalcedony having been heat-treated (Kenoyer 2001 *personal communication*). If that was the case then it might have originally looked like the Ravi Phase blade fragment on the right hand side of Figure 6.6 B, which has same semi-translucent smoky appearance but is tan instead of purple.

I have not yet undertaken any geochemical comparative studies of the purple-hued chert/chalcedonies, the various jaspers or the less abundant types of microcrystalline silicates from Harappa's Ravi and/or Kot Diji phase levels. I have, however, examined lithic assemblages from numerous prehistoric sites around the upper Indus Basin region in an effort to get a sense of what types of microcrystalline silicates were being used by peoples living in the vicinity of the highland areas where the potential sources of those materials were located. Searches of the geologic literature and a number of pertinent observations in the field have also been made. Below, I present some provisional thoughts regarding Early Harappan chert acquisition based on those studies.

Lithic assemblages I have examined from Early Harappan period sites in the Bannu Basin (Lewan, Tarakai Qila) and Gomal Plain (Rehman Dheri, Jhandi Babar) regions of the NWFP are replete with ophiolitic (radiolarian) chert/jasper artifacts (Figure 6.7 A). That material is found just west of those regions in the ophiolites of Waziristan (recall figures 6.4 & 6.5) and the northern part of the Zhob District, Balochistan (*personal observations* 2001). Some of the chert/jasper tools from Ravi Phase levels at Harappa appear as if they *could* be from ophiolitic sources. Jaspers and/or colorful types of chert can also be found

in the Salt Range and northern Rajasthan regions (Figure 6.7 B & C), although I have observed that those usually are of very poor quality (i.e., highly fractured and/or brittle). Still, such material can sometimes be used to make tools, as is evident by the worked chert and jasper debris (Figure 6.7 C) covering the dunes at Gidali (N27º 47’ 25”, E 76º 03’ 37”) in the Sikar District, northern Rajasthan. The people who left behind those remains were either content or compelled to make do with the locally available (Kishore Raghubans *personal communication* 2003) low quality stone. Despite being far removed from any chert sources the early residents of Harappa clearly had more and better options.

Figure 6.7: [A] – ophiolitic chert blades from Rehman Dheri; [B] – the fractured and brittle chert of the Amb Formation, central Salt Range; [C] – chert/jasper cores and flakes at Gidali, northern Rajasthan



I have yet to encounter any stone that even remotely resembles the purple-hued chert/chalcedony from Harappa while doing geologic field studies in Pakistan and Indisia. However, I have seen this exact same material in collections from two other Early Harappan Period sites in the upper Indus Basin region and I suspect it is present at many more. On display in the Kalibangan Museum and pictured in a full color plate in the recently the published report (Bala 2003: 223-228; Plate XXXVI) for that site in western Rajasthan are 25 purple-hued chert/chalcedony microliths that look almost as if they could

have been excavated from Ravi Phase levels at Harappa. I have also examined tools of identical form and appearance among the artifacts that Aasim Dogar recovered at in the Hakra Culture site of Tala Wala Ther in Cholistan (Dogar 2001). Some of the colorful lithics that Mughal described (1997: 68, Plate 43) as being associated with other Hakra sites in that region are likely more of the same. A "microlith of chalcedony" reported in Period 1 (Early Harappan) levels at Banawali (Bisht 1987: 136) is possibly this material as well. I strongly suspect that this distinctive type of chert/chalcedony will eventually be identified at many more sites of this period across the upper Indus Basin region.

No purple-hued chert/chalcedony artifacts were among the lithic assemblages I examined from sites in the NWFP and, therefore, I doubt this type of material was derived from a source in that direction. In addition, although its translucency and visible internal patterning provides the material with a very agate-like appearance, it is quite unlike the agates that I have seen in Gujarat or from elsewhere in the Deccan Traps. There are, however, other agate/chalcedony-bearing volcanic "trap" formations in South Asia. Significantly, two of those are located directly north of the upper Indus Basin: the Khewra Trap in the eastern Salt Range (Jan and Faruqi 1995) and the Pir Panjal Trap of Kashmir (Wakhaloo 1979). Chalcedony geodes have been reported in both of those formations (Wadia 1928: 240; Wynne 1878; 75) and this is one reason why I believe them to be the most promising candidates for the source(s) of the Early Harappan purple-hued chert/chalcedonies. The other reason is that the earliest residents of Harappa clearly had connections to both regions where those formations are located. There are Kot Diji Phase sites throughout the Salt Range (Dar 2002) and excellent evidence (Saar 1992: 13-14) for

Kot Dijian or "Late" Kot Dijian interaction with Northern Neolithic peoples living just to the east of the Pir Panjal Range in the Kashmir Valley. The black-brown chert brought to Harappa during the Early Harappan Period almost certainly comes from the Salt Range (I demonstrate this in the next section) and apparently so did some of the alabaster used at that time (demonstrated in Chapter 10). Also the earliest (Ravi Phase) lead artifact found Harappa is isotopically analogous to lead from sources in Jammu and Kashmir (see Chapter 12). Finally, it is worth mentioning that the only reported occurrences in South Asia of novaculite – the white microcrystalline silicate that is occasionally found in Early Harappan levels at Harappa and which I also saw examples of in the Tala Wala Ther collection, are located in Pir Panjal Traps of Kashmir (Dhall et al. 1977).

Black-brown chert

The overwhelming majority of chert artifacts at Harappa are tan to gray colored in appearance. When tools or debris fragments composed of a macroscopically different type of chert are encountered, such as those discussed in the preceding section, they stand out dramatically. Occasionally these different types are found on the site's surface or in strata that have been disturbed. Usually, however, they are met with in trenches where excavations have reached levels *below* the site's Period 3 or Harappa Phase occupation. Most prominent among the distinctive Early Harappan period cherts is the type that will be referred to here as *black-brown* chert. Like the other two "main" types, black-brown chert is actually quite variable in appearance. Nine examples are pictured in Figure 6.1, numbers 16 through 24. The color of this chert type ranges from black (#24) to a medium-brown color (#17). Many examples exhibit the remains of a very light grayish cortex.

HARP excavators immediately recognized that black-brown chert was closely associated with the Early Harappan Period occupation at Harappa (Dales and Kenoyer 1990a: 248). Prof. Kenoyer has recently pointed out, however, that there *could* be sporadic occurrences of this material in the site's later occupational phases. Although I did not come across any examples the black-brown type among the 161 chert artifacts from Period 3A or the 30 from periods 4/5, as I have stated above, time did not permit me to individually examine each of the 8,400 or so examples from periods 3B and 3C. For those, I made only a quick assessment by looking through the transparent plastic sample bags in which they are stored (grouped by excavation lot and artifact type). If any items among the tan-gray chert flakes, chunks and blades within in the bags had stood out, I would have removed it and inspected it closer. Nothing did, but clearly these assemblages deserve a much more detailed examination of than the cursory look I gave them. Still, if there are any tools or fragments composed of the black-brown type belonging to periods 3B and 3C, I suspect they constitute an extremely small percentage of those assemblages.

Nine black-brown chert artifacts (Figure 6.1: 16 through 24) were selected for a geologic provenience study using INAA. Full details (their HARP numbers, contexts and trench information) for each one can be found in Appendix 6.1. Of the nine artifacts, four each are from periods 1 and 2 levels while one is from a disturbed context. The eight samples from secure contexts probably represent around a 5% to 10% sample of the total number of black-brown chert artifacts from their respective chronological sub-assemblages. The nine artifacts were compared to samples collected from three potential sources of black-brown chert located in northwestern South Asia.

Potential sources of black-brown chert

Prior to this study, the black-brown chert used to make tools during the Early Harappan Period at Harappa was thought to have probably come from sources to the west of the Indus Valley in Balochistan (Meadow and Kenoyer 2001: 24). This is not an unreasonable assumption as chert of this description is known to occur widely across that region (Aubry et al. 1988). Still, the assumption had never been tested and so, beginning in mid-2000, I started to seek out potential sources of that material and collect samples for comparative studies. There are, in fact, many geologic formations surrounding the Indus Valley Basin where dark colored cherts occur that, to varying degrees, resemble the black-brown type from Harappa. However, as I previously pointed out, sources of homogeneous unfractured material suitable for making long blades and other tools of the quality used by Harappans are few and far between. In the end, I located three sources or source formations where excellent to just mediocre quality black-brown chert existed.

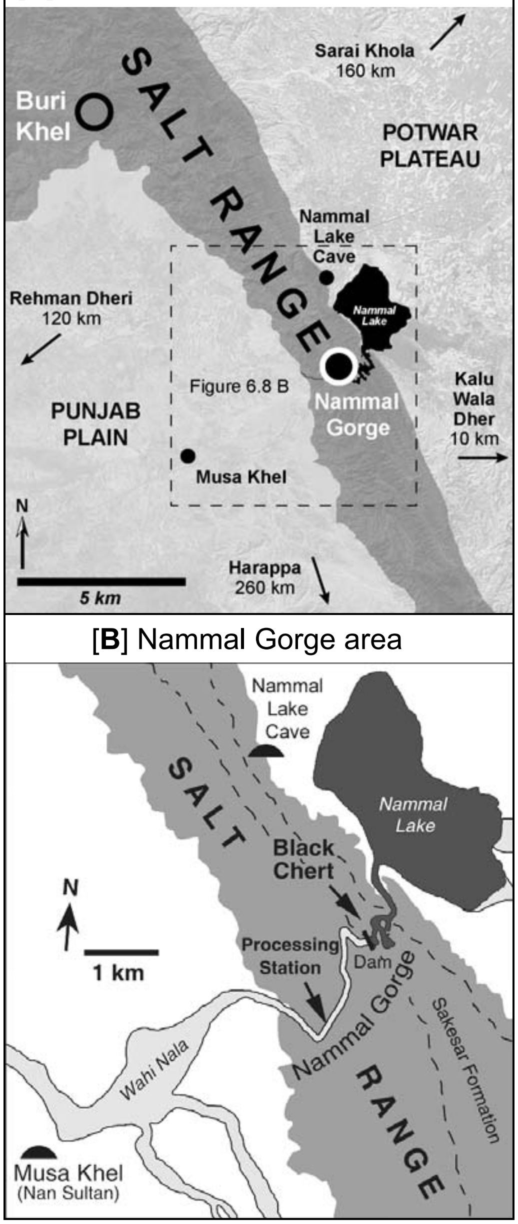
Sakesar Limestone, Salt Range, Punjab

In November of 2000, I with undertook an extended period field research with Dr. Syed Baqri of the Pakistan Museum of Natural History for the purpose of identifying the potential sources of a wide range of rock and mineral varieties used by Indus Civilization peoples. The initial focus of our efforts was the Salt Range. Chert is abundant in these mountains, which mark the northern extent of the Punjab Plain in Pakistan. The materials that we encountered in eastern portion of the range were highly fractured (recall Figure 6.7 B) and would have been unsuitable for tool making purposes. In the central part of the Salt Range (Figure 6.8 A & B), however, nodules of unfractured chert occur in the *Sakesar*

Figure 6.8: *Central Salt Range*

[**A**] Chert sources and prehistoric sites.

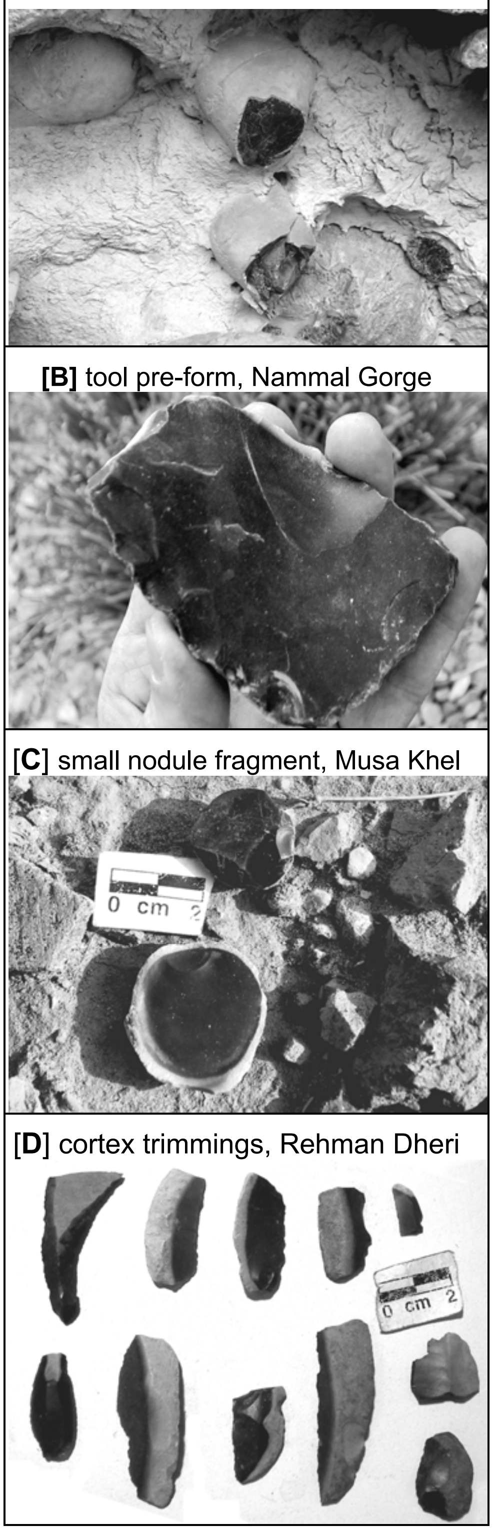
[**B**] Nammal Gorge area



formation. This Eocene age limestone runs the entire length of the range but is thickest towards the west where chert is located in its upper portion (Shah 1977: 80). Based on observations in Nammal Gorge and nearby areas and sites, Dr. Baqri and I suggested that the Sakesar Formation was potentially an important source of chert for the Early Harappan peoples at many sites in the upper Indus Basin region (Law and Baqri 2003).

Nammal Gorge is a short defile that transects the Salt Range near its narrowest point (Figure 6.8 B). At the head of the gorge there is a British Era dam and a small lake created by it (Punjab Government 1915: 197-198). In former times, this would have been an unobstructed passageway linking the Punjab Plain with the Potwar Plateau. It is quite conceivable that Kot Dijian Phase Early Harappans might have traveled via Nammal Gorge to and from sites in the northern Potwar Plateau region like Sarai Khola (Halim 1972) and Hathial (Khan 1983). Evidence that Kot Dijians dwelled in the immediate vicinity has been found on both sides of the gorge at the sites of Musa Khel (Dani 1971: 32), Nammal Lake Cave (Salim 1992: 44-45) and Kalu Wala Dher (Dar 2002).

Figure 6.9: Sakesar chert
[**A**] nodules in situ, Nammal Gorge
[**B**] tool pre-form, Nammal Gorge
[**C**] small nodule fragment, Musa Khel
[**D**] cortex trimmings, Rehman Dheri



Nodules of black-brown chert ranging in size from three to 75 cm occur in the Sakesar limestone near the dam site at the head of Nammal Gorge (N 32° 39' 45", E 71° 48' 1"). They are typically egg-shaped, have a light gray cortex and can easily be extracted from the host rock at places where the Sakesar limestone is soft (Figure 6.8 A). No old quarries or blade workshops like those found in the Rohri Hills of Sindh (discussed below) were identified but a concentration of flakes and possible tool pre-forms (Figure 6.8 B) was observed a few kilometers downstream from the dam. Black-brown Sakesar chert blades, bullet cores, flakes and nodule fragments (Figure 6.8 C) are found among the Kot Dijian artifacts on the surface of Musa Khel, which is situated 3 ½ km to the southwest at the gorge's mouth. I have seen black-brown chert artifacts with the light grey cortex characteristic of Sakesar chert nodules at several Kot Dijian sites outside of the Salt Range region such as Rehman Dheri (Figure 6.8 D), Lewan, Hathial and, of course, Harappa (Figure 6.1 # 17, 18, 20, 22 & 23).

Chert occurs throughout the Sakesar formation (Shah 1980: 26) and so there are doubtlessly innumerable other potential sources in the Salt Range besides Nammal Gorge. Black-brown as well as light-gray colored types can be found in Buri Khel *nala* (stream), 12 km to the northwest of the gorge. I have also collected samples of black-brown chert in the Chichali nala and Saiduwali nala areas, which are located in the extensions of the Salt Range (called the Surghar and Khassor ranges) to the west of the Indus River. Still, chert from Nammal Gorge is the best quality material I have yet located and is, for several reasons, the strongest candidate for the source of the black-brown chert artifacts from Early Harappan levels at Harappa: it is situated in the immediate vicinity of several Kot Dijian Phase sites; it is located along what would have likely been an important avenue of trade and communication within the Kot Dijian core area; and it is macroscopically *identical* to most black-brown chert artifacts from Harappa right down to its cortex. To best evaluate the degree to which Sakesar chert is or is not chemical analogous to those artifacts, however, samples from other potential sources are required for comparison

Great Limestone, Jammu

Figure 6.10: Bedded black chert in the "Great Limestone" formation of Jammu



Black chert (Figure 6.10) occurs throughout the Neoproterozoic *Great Limestone* formation of Jammu (Raha 1984). Samples representing this potential source were collected from two locations around 20 km apart in the Riasi District: Mari nala (N 33° 6' 25", E 74°51' 3") and Jangleghari (N 32° 59' 58", E 75° 2' 32"). Great Limestone chert (at

least that from the two locations I sampled) can, at best, be described as a mediocre material for making tools. Although it is not too terribly fractured, it does seem to only occur as thin (≈1 to 2 cm) uneven beds. Striking a long blade using this material would probably prove difficult. However, there are some smaller fragments of black-brown chert from Harappa that could conceivably be this material (such as Figure 6.1 # 16, 19 & 24). Importantly, both sampled locations are situated just 25 km north-northeast of Manda, where an Early Harappan Sothi-Siswal Phase occupation has been identified (Joshi and Bala 1982). Moreover, I later show that at least some of the steatite (Chapter 7) and lead (Chapter 12) artifacts at Harappa probably came from sources in the Great Limestone of Jammu, which are located nearby (≈ 5 km) the chert occurrences sampled for this study.

Moro Formation, Bolan Pass, Balochistan

Nodular pods of black-gray chert (Figure 6.11) occur in limestone within the Upper Cretaceous *Moro* Formation of central Balochistan (Aubry et al. 1988: 105-106). Samples for this study were collected at a location near Dozan (N 29° 56' 43", E 67° 11' 15") in the Bolan Pass. The quality of Moro chert is mediocre overall. Nodules are firmly affixed in the host rock and are often rife with fractures. Large, fairly homogeneous pieces can occasionally be removed, however. The importance of this source has to do with its position along *the* major route between the Indus Valley and highland Balochistan as well as its proximity (≈ 75km) to the Early Harappans of Nausharo (I) (Jarrige 1993).

Figure 6.11: Black chert pods in Moro limestone, Bolan Pass, Balochistan



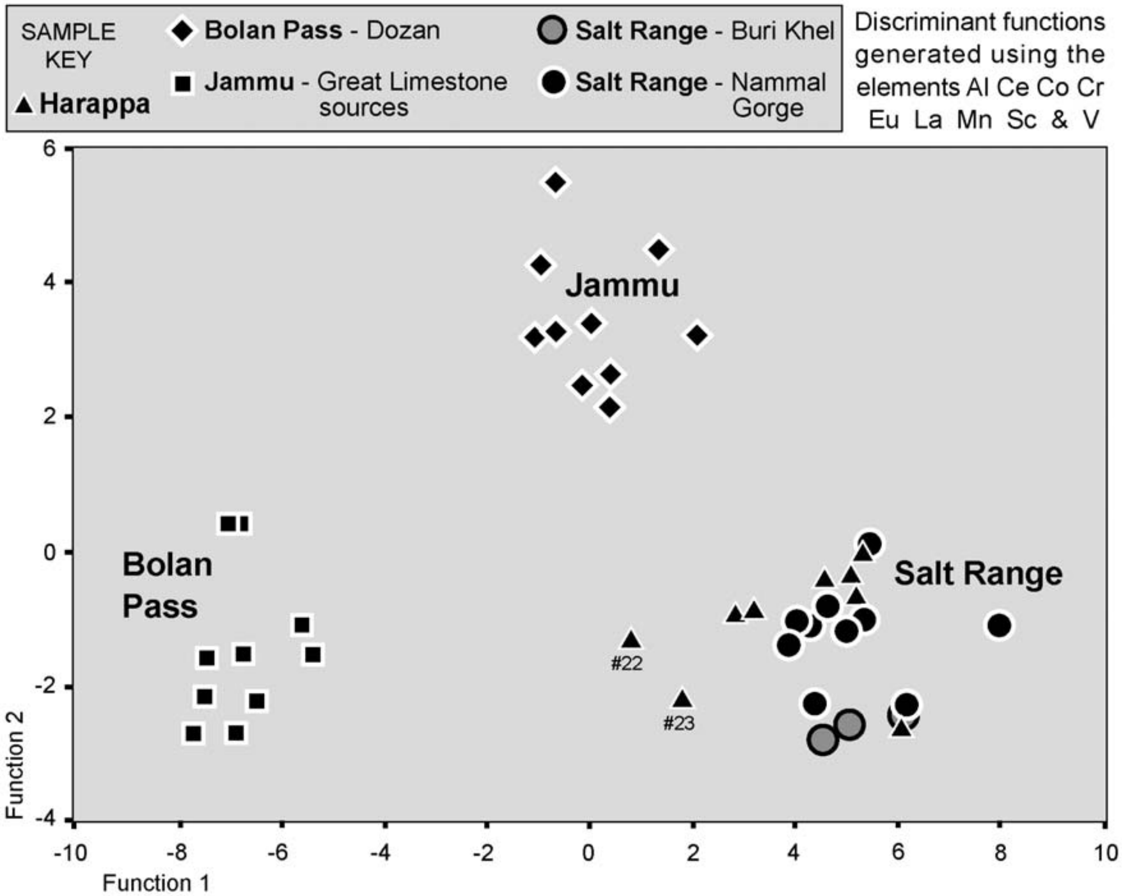
Potential black-brown chert sources not included in this study

There are many potential sources of black-brown chert that are not included in this study. Several more are known to exist in Balochistan (Aubry et al. 1988). Bedded black chert related to that of Jammu occurs throughout the Neoproterozoic Krol Formation of the western Himalayas (Gautam and Rai 1997; Shukla et al. 2005). Deformed beds of dark Proterozoic chert are found within the various formations of the Mawar supergroup in northwestern Rajasthan (Geological Survey of India 2001b: 21). At the Department of Archaeology and Museums' Excavation Branch in Karachi I have seen black to dark brown cherts in the collections from the sites of Allahdino and Ghazi Shah, which are probably coming from Sindh Kohistan and/or the Kirthar Range. Samples from these and other potential sources will eventually need to be obtained and incorporated into future studies

INAA/CDA comparison of black chert artifacts to potential sources

Nine black-brown chert artifacts from Early Harappan levels at Harappa (Appendix 6.1) were compared to samples of chert from three potential geologic source areas using INAA-derived elemental data and canonical discriminant analysis (CDA). Details relating to sample preparation, INAA and CDA have already been presented in Chapter 2. The geologic set includes ten samples of Moro chert from the Bolan Pass, Balochistan and ten samples of Great Limestone chert from two locations (five each from the Mari nala and Jangleghari areas) in the Riasi District of Jammu (Appendix 6.2). Thirteen samples of Sakesar chert from the Salt Range (Appendix 6.3) were analyzed: ten from Nammal Gorge and three from Buri Khel. All samples from each regional source formation were treated as a single group for CDA. Archaeological samples were evaluated as ungrouped cases.

Figure 6.12: Black-brown chert artifacts from Harappa compared to three sources



In Figure 6.12, all analyzed black-brown chert samples (archaeological and geologic) are plotted by their first and second discriminant scores, which were generated using the log normalized concentrations of nine elements in those samples – Al, Ce, Co, Cr, Eu, La, Mn, Sc and V. Excellent visual separation between the datapoints representing the three grouped sets of geologic samples is evident. Application of the leave-one-out classification function resulted in a 97% grouped sample cross-validation success rate, which shows that the three groups are also highly distinct statistically. All of the ungrouped archaeological cases plot among or near the datapoints for the Salt Range

samples. Based on their individual Mahalanobis distances to the centroids of the three geologic groups, all artifacts are predicted to belong to the Salt Range group.

In summary, the sets of black-brown chert samples from sources in the Salt Range, Bolan Pass and Jammu regions that were analyzed for this study are, chemically, very distinct from one another. Of those three sources, the nine black-brown chert artifacts from Harappa are, chemically, most analogous to the chert samples from the Sakesar limestone in the Salt Range. In fact, in the majority instances they appear to be quite closely related to them. A few artifacts (#22 & # 23 – refer to Figure 6.1 and Appendix 6.1), although still predicted to belong to the Salt Range group, do plot somewhat away from that source and from the other archaeological samples. I strongly suspect, however, that those are actual examples of Sakesar chert and not materials from some other unrepresented formation that just so happens to be more chemically analogous the Salt Range group than to the other groups. If the two samples in question looked somewhat out of the ordinary (like say #19) then I might be inclined to think otherwise. However, samples #22 and # 23 look *exactly* like Sakesar chert, right down to their cortex. The fact is that the Salt Range source area is represented by only thirteen geologic samples from two locations. Those samples almost assuredly do not represent the full range of chemical variability that Sakesar chert likely exhibits across the extensive formation in which it occurs or, for that matter, at any one location like Nammal Gorge. A larger, more representative sample set will eventually need to be assembled and analyzed. When it is, those outliers will likely be better defined.

In the end, this INAA study suggests that the black-brown chert acquired by Early Harappan period residents of Harappa came from the Sakesar Formation of the Salt Range.

Tan-Gray (Rohri?) chert

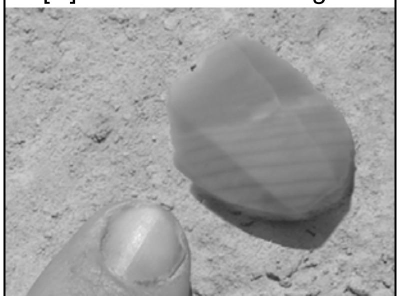
As I stated in the introduction to the preceding section, the vast majority of chert artifacts at Harappa are composed of a material type that has a tan to gray colored appearance. Many of those also possess a highly distinctive banded pattern. Here, these macroscopic variations are collectively defined as the *tan-gray* chert type. Approximately one-third of the roughly 20,000 tabulated tan-gray chert artifacts at Harappa are flakes or other debris fragments like those seen in Figure 6.1 – #1 to 6 and 10 to 15. Although most of remaining two-thirds are tools (blades, drills, awls), a small percentage includes blade cores, objects that may be weight blanks or celt roughouts, an occasional ornament and the characteristically Harappan-style cubical stone weight (Figure 6.13). Tan-gray chert is present in every one of Harappa's chronological phases and from Period 3A onwards it *appears* to have been the only type used at the site. In this section, I evaluate the widely held assumption that this type of chert came from sources in the Rohri Hills of Sindh.

Figure 6.13: Various tan-gray type chert artifacts from Harappa.
[*left-to-right*] blade tools, blade core, weight blank or celt roughout?, bead and cubical weight.



Figure 6.14: “Rohri Hills-like” banded tan-gray chert artifacts

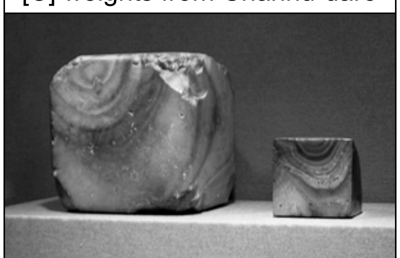
[**A**] chert flake at Rakhigarhi



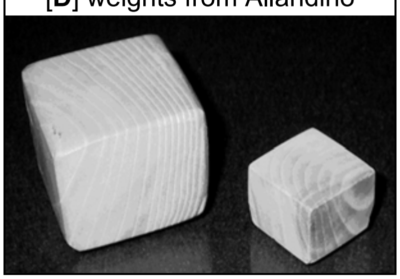
[**B**] chert flake at Ganweriwala



[**C**] weights from Chanhu-daro



[**D**] weights from Allahdino



The extensive chert deposits of the Rohri Hills – a series of Eocene limestone outcrops in northern Sindh, are assumed by many to have been one of the primary sources, possibly *the* primary source, for the high-quality tan and gray chert artifacts found at Indus Civilization sites from Gujarat to northern Afghanistan (Allchin and Allchin 1997: 118; Francfort 1989: 129; Gupta 1984: 420; Kenoyer 1998: 43, 91; Ratnagar 2001b: 64; Rao 1985: 555; Thapar 1993: 11; Vidale 2000: 36-37). Lending weight to those assumptions are the widespread finds of artifacts composed of a banded sub-type (Figure 6.14) that is only known to occur in the Rohri Hills. Various studies (Allchin 1979b; Inizan and Lechevallier 1997; Kenoyer 1984a; Pelegrin 1994) have documented technological and morphological analogies between tan-gray chert blades from several Harappan sites and those produced at workshops in the Rohri Hills during that period (Biagi and Cremaschi 1991). These observations and studies can now be supplemented with direct artifact-to-source chemical comparisons. In this section, fifteen tan-gray chert artifacts from Harappa and one from the site of Harappan site of Nagwada in Gujarat are compared to geologic samples from potential sources in the Rohri Hills, the NWFP, Balochistan and the Punjab (Figure 6.15).

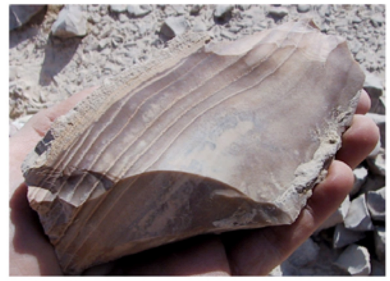
Figure 16.15: Tan-gray chert sources sampled for this study

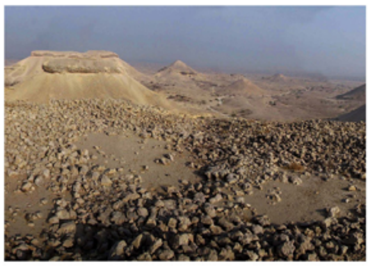
Rohri Hills, Sindh



[A] Rohri

The banded tan-gray chert (right) used for Harappan weights is found at this location, which is rapidly being destroyed (left).





[B] Adam Sultan

Extensive Harappan Period quarries (left) and workshops are found here. Chert cores & debris cover the surface (right).





[C] Kot Diji

Nodules of tan chert erode from the slopes beneath Kot Diji Fort (left). Adjacent to the fort, tan chert blades (right) are found at the prehistoric site of Kot Diji.



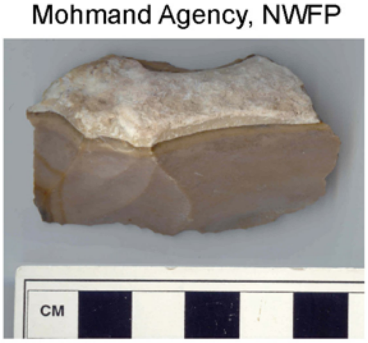


[D] Kandarki Hills

Chert nodules are found in the low hills of the Kandarki area as are blade workshops (right) and a chert heating area (left).



[E] Tan chert
Mohmand Agency, NWFP



[F] Gray Chilton Limestone chert
Kalat District, Balochistan

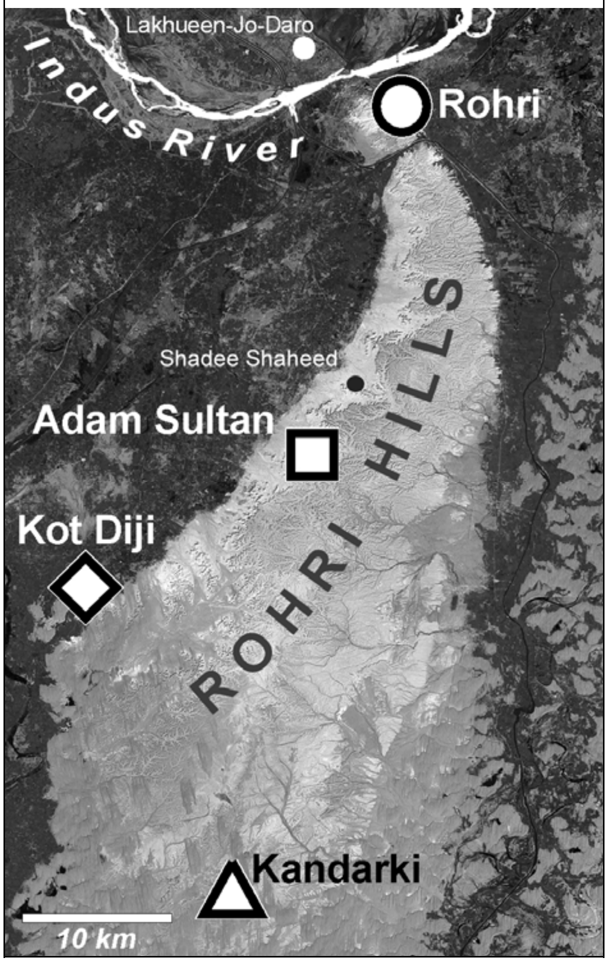


[G] Gray Sakesar chert
Buri Khel - Salt Range



Rohri Hills, Sindh

Figure 6.16: Locations sampled in the Rohri Hills



The significance of chert deposits in the Rohri Hills of Sindh (Figure 6.16) began to become apparent when, in the later half of the 19th century, the existence of large concentrations of cores and flakes was first reported there (Evans 1866; Tremlow 1867; Blanford 1875, 1879). Half a century later, de Terra and Paterson noted (1939: 334-35) that many artifacts found in that region were analogous in form to those that had recently been excavated at Indus Civilization site of Mohenjo-daro, 55 km to the west of the hills. Research in the 1970s by Bridget Allchin and others (Allchin 1976; Allchin et al. 1978) and, more recently, by members of the joint Pakistani and Italian project in the region (Biagi and Shaikh 1994), has subsequently produced a wealth of evidence that documents the intensive exploitation of chert resources in the Rohri Hills from the Lower Paleolithic through the Harappan Period.

In November of 2000, chert from four localities in the Rohri Hills (Figures 6.15 A through D and Figure 6.16) was sampled during field research in that area with G.M. Veesar of the Department of Archaeology, Shah Abdul Latif University, Khairpur.

Rohri

Nodules of tan-gray chert occur on the extreme northern tip of the Rohri Hills (Figure 6.15 A) adjacent to the modern town of Rohri and approximately five kilometers southeast of the Harappan Period site of Lakhueen-Jo-daro (Kazi 1989). The material at this location frequently exhibits a pattern of parallel concentric bands (non-banded types occur also) and is *identical* in appearance to the chert that seems to have been the preferred stone for the making cubical weights used at Harappa (Vats 1940: 361; Figure 6.13 *bottom right*) and many other Indus Civilization settlements (Figure 6.14 C & D). With the exception of a recently reported occurrence near Kandarki along the southern fringes of the Rohri Hills (Nilofer Shaikh *personal communication* 2004), no other sources of tan-gray chert with this distinctive banded pattern are presently known to exists elsewhere in the Greater Indus region. Unfortunately, this source may not exist much longer as the outcrops around Rohri town are rapidly being destroyed by limestone mining operations (Biagi 2006).

Adam Sultan

The chert that occurs in the central portion of the Rohri Hills generally appears to be the most homogeneous (in terms of both color and texture) in the region. Nodules collected at a location near the tomb of Adam Sultan were mostly a uniform medium gray throughout, with the chert grading into a brown-gray within 1 to 2 cm of the cortex. Visually, this material is indistinguishable from that found at the Harappan Period quarries and workshops (Figure 6.15 B) documented slightly farther (≈ 5 km) to the north near the shrine of Shadee Shaheed (Shaikh and Biagi 1999). The ground surface at that location is completely covered with debris from the production of highly standardized chert blades.

Kot Diji

The well-known Early Harappan and Harappan Period site of Kot Diji is situated on the southwestern margin of the Rohri Hills (Khan 1965). Chert nodules can be found in and eroding from, the limestone bedrock of the hill slope directly east of the site just beneath Kot Diji Fort (Figure 6.15 C). Chert at this location tends to have a brown and gray mottled appearance, although some uniform brown examples were observed. Flakes and blades composed of this type can be observed on the site's surface.

Kandarki

The southern extremities of the Rohri Hills consist of intermittent low-lying limestone mesas surrounded by sand dunes called the Kandarki Hills (Figure 6.15 D). The light brown and gray cherts found here tend to contain more inclusions and have a coarser texture than materials found farther to the north. The material is, nonetheless, of excellent quality, as is evidenced by the numerous workshops discovered in the area.

Other potential sources of tan-gray chert

Although the rich, high-quality chert deposits of the Rohri Hills were optimally located with regard to supplying material to settlements across the Harappan realm (i.e., situated in the central Indus Basin along the principal north to south running waterway/trade route), they together constitute only one of many potential source areas around the Greater Indus region from which Harappan consumers could have acquired this resource. For comparative purposes, samples of brown or gray chert were collected from potential sources three additional regions (Figure 6.3 and Figure 6.15 E, F and G) located outside of the northern Sindh area – the NWFP, Balochistan and the Punjab.

Mohmand Agency, Northwest Frontier Province (NWFP)

Little published information exists regarding chert occurrences in the northern part of the NWFP. However, geologic samples from that region in the collections at the Department of Geology, University of Peshawar bear a strong resemblance to the darker types of tan-colored chert found in the Rohri Hills as do many of the chert artifacts from prehistoric sites in the Swat Valley on display in the Swat Museum at Saidu Sharif (*personal observations*). For this study, dark tan chert (Figure 6.15 E) was obtained from a limestone crushing plant at Dand, in the Mohmand Agency. The limestone and the chert at the plant reportedly came from formations near the border of the Mohmand and Malakand agencies (Irshad Ahmad, Centre of Excellence in Geology, University of Peshawar – *personal communication* 2001). Clearly this was not the best way to obtain samples but I felt that inclusion of material from this region in the dataset was essential.

Kalat, Balochistan

Cherts that occur in Balochistan are highly variable, which is not surprising given the large area and diverse geology that the province encompasses. Thierry Aubry and others (1988) made a sizeable collection of samples from across that region, which are now stored at the Department of Geology, University of Balochistan-Quetta. Access to these samples was graciously provided by Drs. Khalid Mahmood and Mehrab Khan of the Center of Excellence in Mineralogy, University of Balochistan-Quetta. In the Kalat District, nodules of yellowish-gray to gray-colored chert are found in Chilton limestone (Figure 6.15 F). For this study, five examples of gray Chilton chert were selected from a set of materials collected near the village of Gajan (ibid.: 103).

Buri Khel, Salt Range, Punjab

In the central portion of the Salt Range, Punjab Province, nodules and fragments of a light gray-colored chert (Figure 6.15 G) are found in the bed of Buri Khel nala. Although I did not locate in situ deposits of this material, it most probably derives from the nearby Eocene limestone of the Sakesar Formation as it was found in association with black-brown Sakesar chert fragments. Fifteen kilometers south of this location, I observed blades made of a light gray chert identical in appearance to the Buri Khel material on the surface of the Early Harappan and Harappan period site of Musa Khel (Dani 1971: 32).

Tan-gray chert sources not included in this study

It is important to point out that there a number of potential tan-gray chert sources that are not included in this study. Southern Sindh is one area that will need to be intensively sampled in the future. Bridgett Allchin and others (1978) reported chert quarries and working floors on a limestone ridge adjacent to Milestone 101 near the modern city of Hyderabad. In that same area, chert beds continue in the Eocene limestone hills to the west of Kotri town (Blanford 1879: 142). Paolo Biagi's recent (2005) surveys there revealed only Paleolithic workshops, which suggest that the exploitation of material from the region probably ceased well before the Harappan Period. The material reported was light brownish gray in color (Biagi 2005: 1). Another occurrence lay south of Kotri at Tharro Hill, where N.G. Majumdar observed (1934: 20-21) "innumerable" chert flakes and cores and suggested that the location was a "centre of flint-knapping industry." To the northwest of Kotri, not far from the site of Ghazi Shah, Majumdar noted (ibid.: 122) a heavy concentration of worked and unworked chert at Bandhni Nai.

Balochistan is also a region where much more exploration for potential chert sources needs to take place. Dr. Syed Baqri recently observed an extensive chert working area while doing palaeontological fieldwork in the Dera Bugti region of east-central Balochistan. Although his examination was cursory, the archaeological remains and the tan-gray chert found there were considered to be very reminiscent of that at similar activity areas in the Rohri Hills (S.R.H. Baqri *personal communication* 2004).

INAA/CDA comparison of tan-gray chert artifacts to potential sources

The fifteen tan-gray chert artifacts from Harappa (Figure 6.1 # 1 through #15; Appendix 6.4) selected for INAA/CDA comparison to the geologic sources described above were excavated from secure contexts ranging from Period 1 through Period 3B on Mound AB and Mound E (Figure 6.2). The samples were judiciously chosen to represent the range of variability evident among artifacts defined as being composed of this material type. A few examples (# 1, 6 & 11) were specifically selected because, although they are tan-gray in appearance, they have a somewhat "un-Rohri Hills-like" texture or cortex.

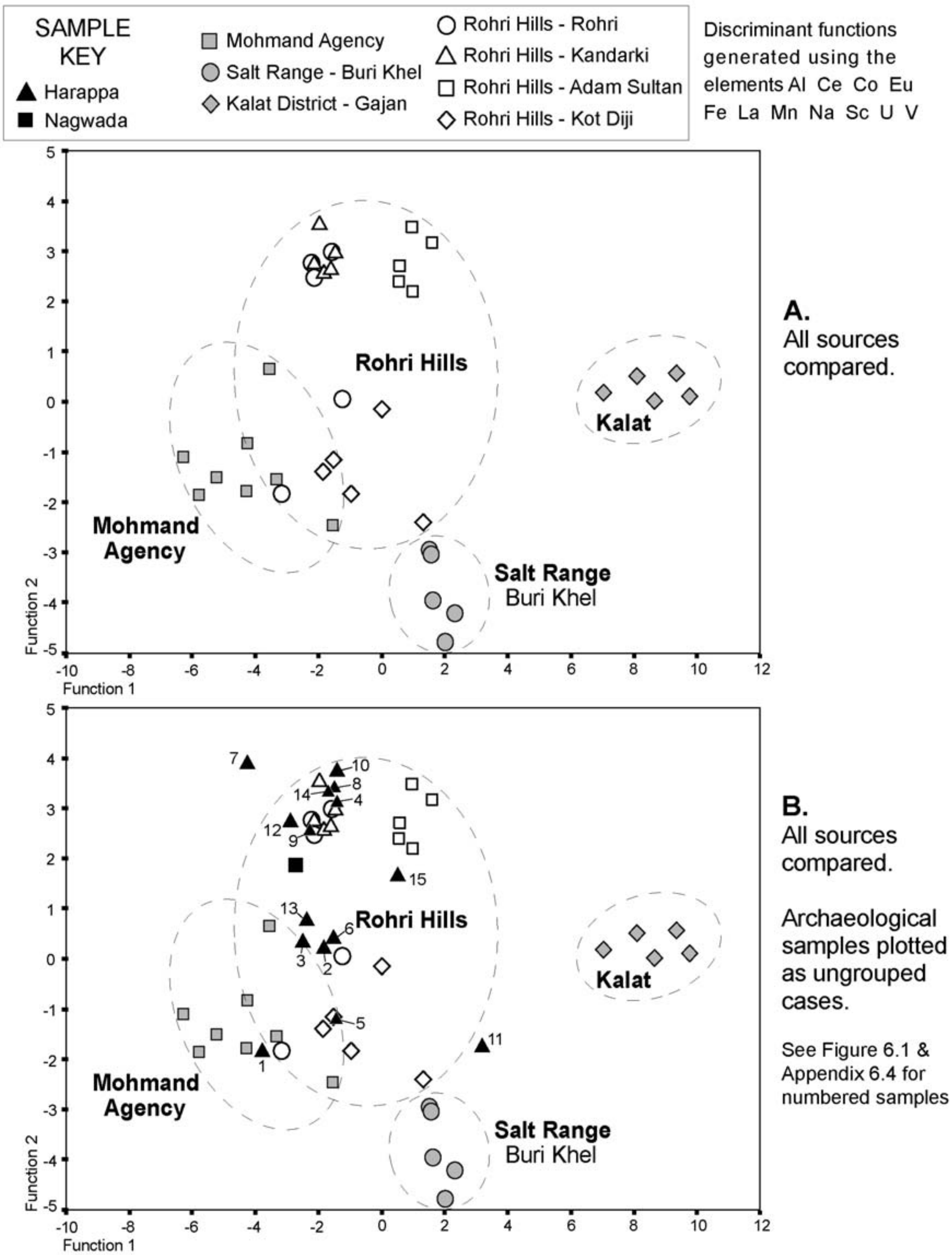
Dr. Kuldeep Bhan of the Department of Archaeology, Maharaja Sayajirao University, Baroda provided the single tan-gray chert blade fragment (Figure 6.1 NGW; Appendix 6.4 bottom row) recovered in Harappa Period levels at the Indus Civilization settlement of Nagwada in northern Gujarat (Figure 6.3). Chert artifacts of this type were found throughout that site's stratigraphic sequence (they are described in Hedge et al 1988 publication as being "ivory" colored). The excavators wrote that "ivory colored chert is not reported from anywhere near Nagwada" and that "it would be interesting to know if they came all the way from the Rohri Hills" (Hegde et al. 1988: 62-64).

The geologic dataset includes 20 tan-gray chert samples from the Rohri Hills – five samples each from the four locations visited in that region (Appendix 6.5). Eight samples from sources in the Mohmand Agency, NWFP and five each from Buri Khel, Punjab and the Kalat District, Balochistan round out the dataset (Appendix 6.6). Details relating to sample preparation, INAA and CDA were presented in Chapter 2. Data for eleven elements (Al, Ce, Co, Eu, Fe, La, Mn, Na, Sc, U and V) are reported in the appendices.

All sampled tan-gray chert sources are included in the initial CDA of the geologic and archaeological datasets (Figure 6.17 A). Although the four Rohri Hills locations are treated as separate groups for the analysis, I have placed dashed ellipse around all samples from that region, as well as ellipses for each of the other three groups, in order to demarcate the approximate areas where the regional sources plot. These ellipses are hand drawn visual guides and do *not* represent statistical confidence intervals. Good visual separation, overall, between the different sources is evident. There is a degree of overlap between samples from Rohri Hills deposits and those from the Mohmand Agency source. The Kalat and Buri Khel sources both group separately, however. Exactly 73.7% of leave-one-out cross-validated grouped geologic cases were classified correctly. The misclassifications that resulted in that percentage were among the Rohri Hills sources (not unexpected as they are from the same broad geologic formation) as well as between samples from two of the Rohri Hills locations (Rohri and Kot Diji) and the Mohmand samples.

When the chert artifacts from Harappa (solid black triangles) and Nagwada (solid black square) are considered as ungrouped cases (Figure 6.17 B), the majority including the Nagwada artifact plot among the geologic samples from the Rohri Hills. The CDA-

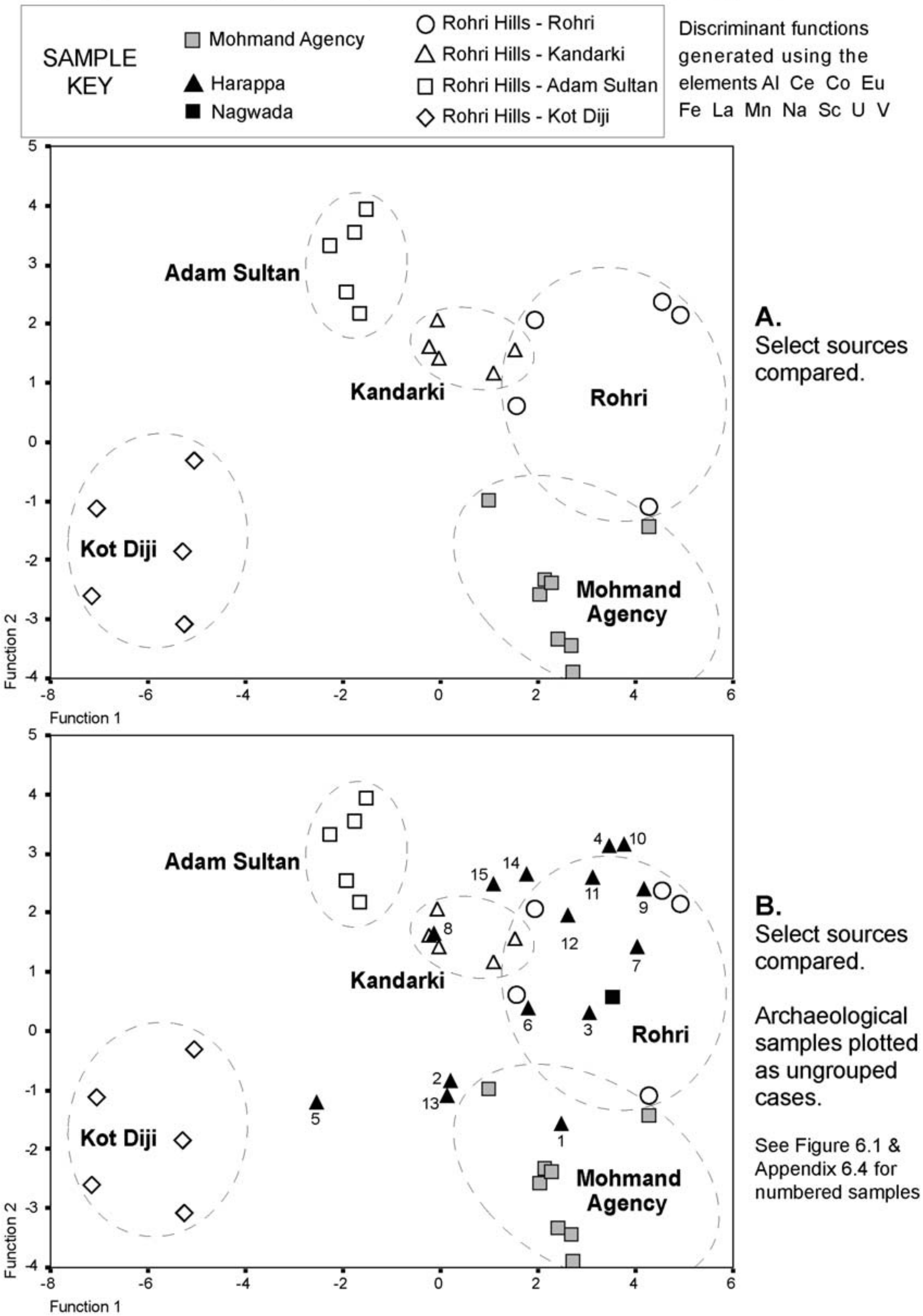
Figure 6.17: Tan-gray chert artifacts from Harappa and Nagwada compared to geologic samples from sources in four regions



predicted group memberships for all samples is one of the Rohri Hills sources (Rohri = 12 artifacts including the Nagwada sample, Kot Diji = 2, Kandarki and Adam Sultan = 1 each). Several artifacts, however, fall in or near the area where samples from the Rohri Hills and Mohmand sources overlap. Since this is an area where misclassification of some cross-validated geologic samples occurred there is the possibility that some artifacts in this area, although predicted by CDA to belong to a Rohri Hills source, could actually be an outlier of the Mohmand source. Sample number 1 (H2001/2939-27) plots especially close to that group and, in fact, was one of the samples that was chosen because it had a somewhat "un-Rohri Hills-like" appearance to it. Similarly, sample number 11 (H96/7500-30) plots away from the main group of artifacts toward the Salt Range samples from Buri Khel. Upon closer examination, this artifact *could* be grayish-colored Sakesar chert and it does come from a context (Period 1) when material of that kind was being used at Harappa.

For the second CDA (Figure 6.18 A), only the Mohmand Agency cherts and samples from the four locations in the Rohri Hills are compared. The Buri Khel and Salt Range groups were removed from the geologic dataset because none of the artifacts from Harappa were predicted to belong to them and they did not overlap with the other sources. Where as the Kot Diji and Adam Sultan groups are distinct, varying degrees of overlap exists between the Kandarki and Rohri sources as well as between the Rohri and Mohmand Agency groups. This time, only 60.7% of cross-validated grouped cases were correctly classified. The lower cross-validation success rate is partially due to the removal the two most geochemically distinct groups (Buri Khel and Kalat) from the dataset and partially due to the misclassification between Kandarki, Rohri and Mohmand samples.

Figure 6.18: Tan-gray chert artifacts from Harappa and Nagwada compared to geologic samples from sources in select regions



Most of the chert artifacts still plot among the Rohri Hills sources (Figure 6.18 B). Ten were predicted by CDA to belong to the Rohri group while three others (numbers 5, 8 and 15) were assigned to the Adam Sultan group. The latter prediction might seem unusual as none of the artifacts appear to fall near the Adam Sultan group on the plot. Recall, however, that group membership predictions are based upon proximity to a group centroid in multi-dimensional space, whereas only two dimensions can be represented on the plot. Interestingly, two chert fragments from Harappa (numbers 2 and 13) are now predicted to belong to the Mohmand group. Although those artifacts may indeed have come from that source, it is possible they are Rohri Hills outliers that just happen to fall closer to the Mohmand group centroid. It is worth pointing out again that the overlap between samples from the Rohri and Mohmand groups contributes, in part, to the misclassification of nearly 40% of the geologic cases. Chert artifacts derived from either of those source regions would be subject to the same risk of misclassification. Significantly increasing the number of geologic samples analyzed may eventually help mitigate this problem by providing a clearer understanding of the geochemical variation in chert deposits both within and between the regions being compared. Nevertheless, it is still possible to state that when artifacts from Harappa are compared to all of the chert deposits examined for this study, they are, on the whole, much more analogous to material from the Rohri Hills (especially the deposit near Rohri town), than they are to any of the other sources. There is limited evidence that the chert used to make a few of the artifacts might have been derived from a source outside of the northern Sindh region, perhaps one in the Mohmand Agency, NWFP. The "ivory" colored chert blade from Nagwada appears to have come from the Rohri Hills.

Chapter conclusion

Geologic provenience studies of chert at Harappa are still at a very early stage. The sample size (Figure 6.19) represented by the 24 artifacts thus far analyzed from the site is miniscule (0.11%) in relation to the total number of chert artifacts recovered (and this is not taking into account the fact that the amount recovered assuredly represents the barest fraction of what actually exists at the site). Sample size is slightly better (0.25%) when considered as a percentage of chert artifacts just from secure contexts and even quite good for certain chronological sub-assemblages (Period 2 at 6.67% is the best sampled). Hundreds more artifacts will need to be analyzed, however, in order to obtain a sample that is reasonably representative both temporally and spatially (75 analyses are needed for just a one percent sample of the recovered Period 3C sub-assemblage). At this point it is simply not possible to say much about site-wise synchronic variations in chert source usage. Discussions of diachronic source usage are possible with the understanding that supporting INAA data is limited. That being said, the INAA results along with general observations about the composition and distribution of the chert assemblage at Harappa have provided important new insights into Early Harappan and Harappan Period chert acquisition networks. Some past assumptions about where certain types of material were obtained clearly need to be revised while others can now be

Figure 6.19: Percentage of chert artifacts sampled by context

Period	total chert artifacts	number analyzed	percent sample
1	625	7	1.12%
2	105	7	6.67%
3A	161	3	1.86%
3B	932	6	0.64%
3C	7,472	0	0%
4/5	30	0	0%
Surface & disturbed	11,642	1	0.009%
All from secure contexts	9,324	23	0.25%
Total	20,967	24	0.11%

supported for the first time with direct artifact-to-source comparative data. The major findings and evident trends, in summary, are as follows:

The founders and early residents of Harappa acquired three main types of chert. Based on field observations, a review of the geologic literature and studies of lithic assemblages at other Early Harappan sites, I have concluded that the most probable source or sources of the purplish-hued type of chert/chalcedony used during periods 1 and 2 are the Khewra and/or Pir Panjal volcanic trap rock formations located approximately 225 km and 400 km to the north of the site respectively. Field reconnaissance in the eastern Salt Range and Kashmir, along with the eventual analysis of chert/chalcedony samples from those regions, will be required to confirm this, however. The black-brown chert used during the same Early Harappan periods was almost certainly derived from sources beginning around 250 km to the northwest of the site in the Sakesar limestone of the central and western Salt Range, rather than from sources in Balochistan as previously thought. Artifacts of this type at Harappa are identical in appearance to Sakesar chert and the INAA results indicate that, of the three regional sources compared, they are most geochemically analogous to samples of black-brown chert collected from the Nammal Gorge / Buri Khel area of the central Salt Range. Furthermore, this exact same macroscopic type of chert was being exploited by peoples living at several Early Harappan Kot Dijian Phase sites in the immediate vicinity of the Salt Range. INAA results suggest that tan-gray chert from the Rohri Hills of northern Sindh was being transported 500 km to Harappa as early as the Ravi Phase (Period 1) and continued to be acquired by the site's residents through at least the mid-urban phase (Period 3B). There is also some indication that examples of another

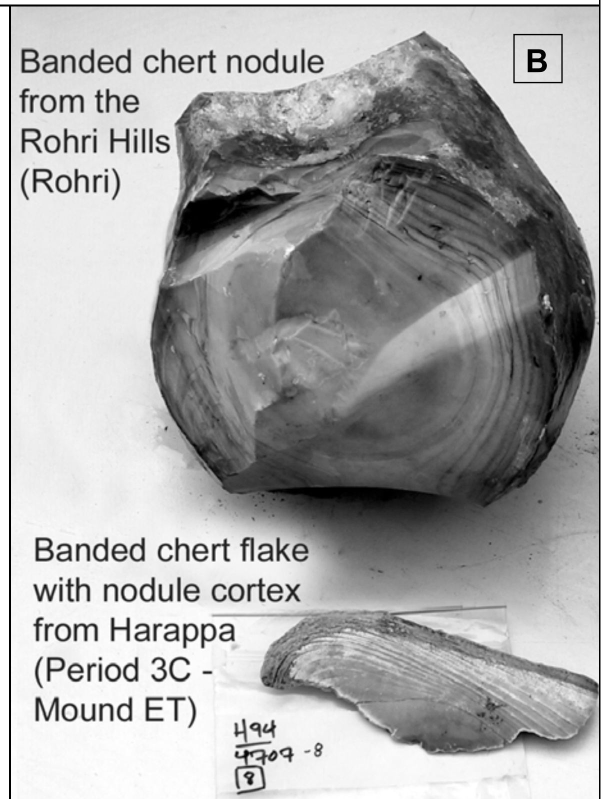
type of tan-gray chert, which chemically resembles that occurring in the Mohmand Agency of northern Pakistan, *could* be present in Harappa's lithic assemblage. However, many more analyses of comparative source samples from the NWFP and northern Sindh are needed in order to determine if those indeed represent a different source or are just variants of Rohri Hills chert. The INAA results indicate that the single analyzed tan-gray chert blade fragment from Harappan Period levels at Nagwada in Gujarat was probably also derived from the Rohri Hills. This small but important piece of evidence, together with that results provided by the samples from Harappa, lends support to assertions that tan-gray chert from that specific part in northern Sindh was being widely distributed across the Greater Indus region and beyond during the Harappan Phase of the Indus Tradition.

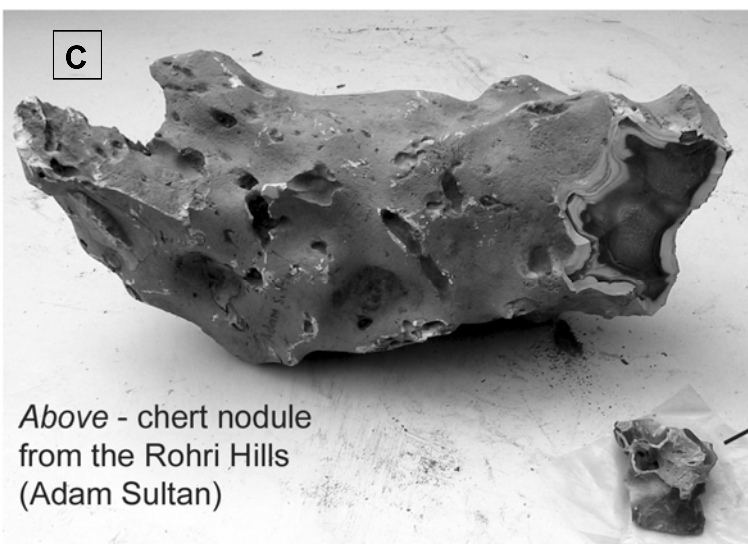
Much of the tan-gray chert found at Indus Civilization settlements was probably transported to those sites in the form of finished, standardized long blades (Inizan and Lechevallier 1997). These were clearly produced on an enormous scale at Rohri Hills quarry/workshops dated to the Harappan Phase (Biagi and Cremaschi 1991; Biagi 1995). At Harappa, however, at least some chert evidently was acquired in unfinished form, probably as unworked, or perhaps marginally reduced, nodules. On average around six percent of the chert artifacts recovered at the site are wholly or partially composed of the cortex that forms on the exterior of such nodules (Figure 6.20 A). Over 80% of artifacts with cortex are flakes, which would indicate that nodules were being reduced at the site, as opposed to just blades with cortex, which could still have arrived at the site in finished form. When large-sized chert chunks and flakes with cortex from Harappa are directly compared with the Rohri Hills nodules collected for this study (Figure 6.20 B & C), the

Figure 6.20: Chert artifacts with cortex and nodules fragments at Harappa

A. Percentage of artifacts with cortex in Harappa's chert assemblage through time

Period	total chert artifacts	number w/ cortex	percent w/ cortex
1	625	24	3.84%
2	105	8	7.62%
3A	161	10	6.21%
3B	932	35	3.76%
3C	7,472	368	4.93%
4/5	30	6	20.0%
Surface & disturbed	11,642	828	7.11%
ALL	20,967	1,279	6.10%





Below - chert nodule fragment from Harappa (Period 3C levels below the Mughal Sarai)



archaeological fragments are so similar visually that they appear as if they could have been struck directly from the geologic samples. Whole, unworked nodules, especially those

from the northern tip of the Rohri Hills, would have been desired by makers of cubical stone weights as the most prominent banding occurs nearer the cortex. Nodules weighing 30 kg or more are not uncommon in that geologic formation (*personal observations* 2001). Transporting stones of that size over 500 km to Harappa easily could have been been accomplished by means of bullock cart or river-craft. In Chapter 11, I show that limestone ringstones weighing more that 100 kg were likely being transported 800 km to the city from the northern Gujarat region during the latter part of Period 3.

What, ultimately, is most revealing about chert usage at Harappa is the way in which the variety of types decreased over time – from three main types plus several minor types during the Ravi Phase to the exclusive (or very nearly so) use of Rohri Hills chert during the Harappa Phase. This change cannot be explained by a diminishment of material acquisition networks stretching toward the Salt Range and beyond, as steatite (Chapter 7), vesuvianite-grossular (Chapter 9), alabaster (Chapter 10) and lead (Chapter 12) continued to be acquired from regions far to the north of Harappa during Period 3. That the shift to the use of one chert source/type occurred at the transition to Harappa's urban phase and appears to have been an extra-regional phenomenon is, no doubt, highly significant. Ratnagar concludes (2001a: 354) "that the distribution of [Rohri] chert blades reveals not trade according to variable regional demand but a regional distribution process handled by the rulers" of Indus society. That is certainly a possible explanation and one which I explore further in the discussion section of Chapter 13.

In the next chapter, I examine steatite – the single most abundant material variety in Harappa's rock and mineral assemblage.

Chapter 7

Steatite acquisition networks

Chapter 7 – Steatite acquisition networks

Chapter introduction – "steatite civilization"

Steatite – a rock composed primarily of the mineral *talc* (hydrous magnesium silicate) in its massive form, was undoubtedly a material of tremendous importance at Harappa. Artifacts made from it comprise nearly 40% of the site's rock and mineral assemblage. This soft (Mohs ≈ 1 – 2.5), easily carvable stone was not only used for the mass-production of common items, notably the ubiquitous wafer-like disc bead (Figure 7.1 A) and the almost impossibly small "micro-bead" (note the human hair in Figure 7.1 B), but also for the closely controlled creation of objects with significant political and/or economic value such as stamp seals (Figure 7.1 C) and inscribed tablets (Figure 7.1 D). Steatite artifacts of one kind or another have been reported from practically every excavated Indus Civilization site. It has been observed that the aforementioned beads are so common that their presence alone could almost be considered a marker of a settlement's "Harappan" character (Vidale 1989c). The archaeometrist and renowned bead scholar Horace Beck even went as far as to characterize Indus society as a "steatite civilization" (cited in Vidale 2000: 59).

Figure 7.1: Various types of steatite artifacts from Harappa (*note - mixed scales*)

A. Disc beads	**B**. Micro-beads	**C**. Unicorn stamp steal	**D**. Inscribed tablets



In terms of addressing the lines of inquiry outlined in Chapter 1, there are few rocks or minerals in Harappa's assemblage that hold as much promise as steatite (for a view to the contrary see Asthana 1993: 274). Sources of the stone are found in every major region surrounding the Indus Basin (Figure 7.2). However, in comparison to some of the other widespread rock varieties examined in this dissertation (such as the different types of grindingstone, limestone and alabaster), occurrences of steatite tend to be much more geographically circumscribed within the regions where they are found. Steatite provenience data may, therefore, allow us to more precisely identify the region or regions with which Harappans were interacting (either directly or indirectly) when acquiring this material (Question 1). Furthermore, at different times during its development and existence, the Indus Civilization bordered numerous potential steatite source areas (Law 2002) and, at Harappa, the raw material is present in abundance throughout site's chronological sequence. This material sub-assemblage is, therefore, particularly well suited for examining diachronic change in inter-regional interaction networks (Question 2). Finally, the production of steatite objects was an activity that took place in each of Harappa's major habitation areas. In contrast to chert artifacts during the site's urban phase (Period 3), raw steatite exhibits a great deal of visual variability, which *could* indicate that multiple sources were used. This makes steatite a potentially excellent material for detecting intra-site variations in source area access that may be evidence of competition between residents of different parts of the site through the control of essential resources (Question 3). It is for all of the above reasons that I placed a great deal emphasis on the investigation of this variety of stone while conducting research for this dissertation.



Figure 7.2: Sites, regions, and steatite deposits discussed in this chapter.

This chapter is an account of my attempt to systematically identify the geologic sources from which residents of Harappa and certain other Indus Tradition peoples acquired steatite. It is presented in four sections. The first begins with a brief overview of steatite use in the Indus Tradition. I then provide details regarding this material sub-assemblage at Harappa and relate which samples from it were selected for geologic provenience analysis. I also provide details on steatite artifacts from seven additional archaeological sites – Mohenjo-daro, Nausharo, Mehrgarh, Gola Dhoro, Nagwada, Tepe Hissar and an unknown site in the Loralai district of northern Balochistan, which I was very fortunate to have been able to include in this study. In the second section of this chapter, I highlight certain aspects related to the petrogenesis of steatite that are important for understanding where deposits of the stone occur and are also necessary for evaluating the geochemical data produced in the analysis of artifacts and source material. I then provide a detailed, region-by-region review of steatite occurrences in the Greater Indus region. In the third section, I present the results of a geologic provenience analysis the steatite artifacts. One hundred forty artifacts from Harappa, along with 37 artifacts from the seven additional sites were analyzed using instrumental neutron activation analysis (INAA). These were compared, using canonical discriminant analysis (CDA) and cluster analysis (CA), to data from 442 geologic samples collected from 37 individual deposits of steatite from around the Greater Indus region. The analyses provided results that were, in many ways, surprising. The source composition of the steatite assemblage at Harappa was far less variable, both synchronically and diachronically, than anticipated. It also became apparent that Indus Tradition craftspeople were, in general, using raw material from a very

specific kind of geologic deposit. In the fourth and final section, I provide a summary and discuss the implications of the provenience study results. I also argue that technological-aesthetic considerations (the need for stone that would become white when heat-treated), rather than proximity to sources, dictated which deposits Harappans acquired steatite from. All sites, regions and sources discussed in this chapter are identified on Figure 7.2.

Steatite in the Indus Tradition

The first evidence for the use of steatite by Indus Tradition peoples goes back to the very earliest (ca. 7000 BC), pre-ceramic Neolithic levels (Period I) at Mehrgarh, where small cylindrical beads composed of black-colored steatite are present in an ornament assemblage predominantly made up of shell beads (Barthélémy de Saizieu and Bouquillon 1994: 47-48). The stone soon thereafter became the most abundantly utilized ornamental material at the site and it remained so throughout the long Neolithic/Chalcolithic sequence there and at nearby Nausharo (Barthélémy de Saizieu and Bouquillon 1997: Figure 1). During that time, there were numerous technological innovations involving steatite (documented in Barthélémy de Saizieu and Bouquillon 1994, 1997; Miller 1999; Vidale 1989a, 2000); the most important of which was the heat-treatment of the stone to increase its hardness and change its color to white (this process is discussed in detail in the final section of this chapter). Indus Civilization craftspeople inherited these innovations and themselves produced new ones. The recovery of "talc-coated clay dishes" at Harappa likely indicates that they had become aware of steatite's heat-resistant (refractory) properties (Miller 1999: 419-422). In addition to the beads, seals and tablets mentioned in the chapter introduction, steatite was used to create a wide range of other items such as

amulets, pendants, cubical weights, inlays, miniature vessels, figurines and small statues (including the famous "Priest-King"). Horace Beck wrote (1934: 69) that the steatite objects produced by Indus Civilization craftspeople were remarkable "not only in their number and variety, but also in their extreme beauty and perfection of execution."

The steatite assemblage at Harappa and samples selected for this study

Roughly 22,000 steatite artifacts have been recovered at Harappa (21,872 have been tabulated to date but I say "roughly" because more are constantly being added to the total as large surface collections and micro-debitage samples are evaluated). About 80% of those are beads composed of heat-treated steatite or steatite-paste (Kenoyer 2005a: Table 2). The remaining 20% or so include all of the other items mentioned in the preceding section, unfinished objects (again mostly beads), manufacturing debris and pieces of unworked steatite. It is not necessary to provide a detailed breakdown of the spatial and temporal distribution of steatite artifacts at Harappa because, like chert artifacts, they are *everywhere*. They have been recovered (in abundance) in every excavation trench placed at the site and from secure contexts representing each of its chronological phases and sub-phases. This is not to say that the assemblage is completely uniform across time and space. The production of glazed steatite button seals, for instance, does not begin until Period 2 (Meadow and Kenoyer 2001) while incised steatite tablets do not appear until the middle of Period 3B (Meadow and Kenoyer 2000). Also, there is evidence that seals and tablets were only made and used in certain parts of the site (ibid.; Kenoyer 1992a). New styles of steatite beads emerged over time as new technologies were developed (Kenoyer 2005a). However, as a material variety, steatite was, in every sense of the word, *ubiquitous* at Harappa.

Out of the 22,000 steatite artifacts at Harappa, only around 3,000 (again roughly) have not been heat-treated. In the section on steatite in Chapter 4, I discussed the physical changes that result when stone of this variety is heated and I further elaborate on that process in the concluding section of this chapter. Although much less abundant, unheated (I will use the terms "unfired" and "raw" as well) steatite artifacts have also been recovered from each phase and in every part of the site (Figure 7.3). It is this sub-assemblage that is best suited to be the subject of geologic provenience investigations as the original mineralogical structures of the artifacts in it are unmodified by heat.

Figure 7.3: Spatial and temporal distribution of 2990 *unfired* steatite artifacts at Harappa

Mound ↓ / Period →	**1**	**2**	**3A**	**3B**	**3C**	**4/5**	**surface & disturbed**	*total*
F	.	.	.	13	63	.	20	*96*
AB	160	63	264	31	44	6	86	*654*
E	.	8	184	71	201	.	197	*661*
ET	.	.	.	13	979	.	453	*1445*
cemetery & off mound	.	.	.	4	103	.	27	*134*
total	*160*	*71*	*448*	*132*	*1390*	*6*	*783*	***2990***

It is clear from even a cursory inspection of the sub-assemblage of unfired steatite artifacts at Harappa that there are multiple, macroscopically distinct kinds of material within it. Massimo Vidale has speculated (2000: 56) that such variability (caused by secondary minerals in the rock) may be indicative of materials from different geologic deposits. Moffat and Buttler found (1986: 114) that visual comparisons of artifacts made from raw steatite to geologic samples was more effective (at least in their study area) than INAA in efforts to identify possible sources. For these reasons, it was deemed practical to create a macroscopic typology for unfired steatite at Harappa. This was undertaken using

Figure 7.4: Seven main macroscopic types of raw steatite at Harappa (descriptions made using a *Munsell Rock-Color Chart*).



Type A. Grayish yellow (5Y 8/4) to Yellowish gray (5Y 7/2) to Brownish gray (5YR 4/1)
Type B. Grayish black (N2) to Black (N1) with Yellowish gray (5Y 7/2) patches
Type C. Light olive gray (5Y 5/2), sometimes with olive black (5Y 2/1) patches and swirls
Type D. Moderate brown (5Y 3/4) to Dark yellow brown (10YR 4/2)
Type E. Black (N1)
Type F. Med. Light gray (N6) to light gray (N7)
Type G. Dark reddish brown (10R 3/4) to Very dark red (5R 2/6)

a Munsell Rock-Color Chart (Rock-Color Chart Committee 1995). Seven main macroscopic "types" of steatite were defined (Figure 7.4) after examining around 300 unfired steatite artifacts (roughly 10% of that material sub-assemblage) from surface collections and from secure contexts ranging from periods 1 through 5. As will most such typologies, the categories I created are highly subjective. They could be lumped together or split in any number of other ways. For instance, Type B might simply be an intermediate form between types E and A. Type G could be divided into several types as artifacts classified as belonging to it range from a dull muddy red brown to a deep red. Be that as it may, I would argue that these seven "types" represent very well the main visual variations exhibited by the raw steatite used at Harappa. Whether or not each is actually indicative of steatite from a different geologic source is something that was

unclear when I created the typology, however. Although I examined only a portion of the sub-assemblage, there did not *seem* to be any temporal or spatial patterning in the distribution of the "types" that might suggest Harappans in different periods or parts of the sites used only certain "sources" (all types are represented on each mound and most types are present in each phase). Later, while conducting geologic field studies, I came to realize that the macroscopic appearance of steatite can be highly variable within a single deposit and even in an individual hand sample. It was becoming apparent that my typology might not end up having much utility in terms identifying the source of this type of stone. Still, I also observed that there are some highly distinctive and *recognizable* steatite varieties around the Greater Indus region (such as certain sub-varieties from the Las Bela area of Balochistan, which I have been able to identify on sight in jeweler's cases from Karachi to Rawalpindi). I have, therefore, included the typology here and, later in the chapter, will be examining how it holds up against geologic provenience determinations made using INAA.

When selecting artifacts from Harappa's unfired steatite assemblage for geologic provenience studies, I tried to mainly choose from among the 700 or so fragments of *unmodified* stone recovered at the site; the reasons being, 1) I wanted to avoid subjecting any finished or semi-finished artifacts for destructive INAA whenever possible and, 2) I did not wish to damage any worked surface on examples of manufacturing debris. The study of saw marks on the latter artifact type has already provided valuable insights into the changing technological capabilities of Harappan beadmakers (Kenoyer 1997b). In the around three dozen instances when I did sample manufacturing debris (this was almost always when it was the only kind of raw steatite artifact available from a particular location

and/or chronological context) great care was taken to avoid damaging any worked surface. In the end, 135 unmodified fragments or pieces of debris were sampled for this study.

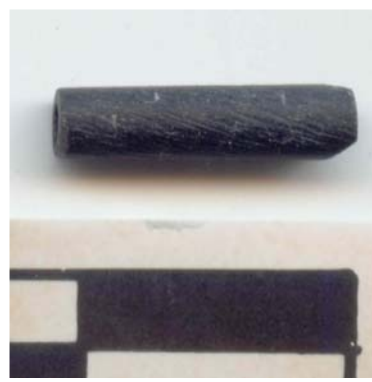
In spite of my hesitation to sample finished or semi-finished objects, there were a few times when I could not pass on an opportunity to analyze a special artifact (Figure 7.5). The first of these is what appears to be an unfinished steatite stamp seal (H96/7257-46) that broke during the manufacturing process (Figure 7.5 A). It was recovered from a street deposit exposed in Trench 37 on Mound F and dates to Period 3B. The face of the seal had not yet been carved and there were still saw marks on its exterior edge. Using a drill with a fine tungsten carbide bit, I took a sample for analysis from the broken side of the seal.

Figure 7.5: Special unfired steatite artifacts from Harappa analyzed for this study.

A. Three views of a broken, unfinished seal (H96/7257-46). Front (left image), sawn edge (middle), broken side (right)



B. Cylindrical bead from Tr. 39, Mound AB (H96-7467-658)



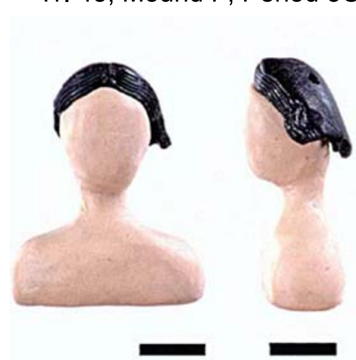
C. Disc bead blanks, Tr. 54, Mound E (H2000-2301-176)



D. Disc bead blanks, Tr. 54, Mound E (H2000-2301-177)



E. Black wig (H98/8668-2) from Tr. 43, Mound F, Period 3C



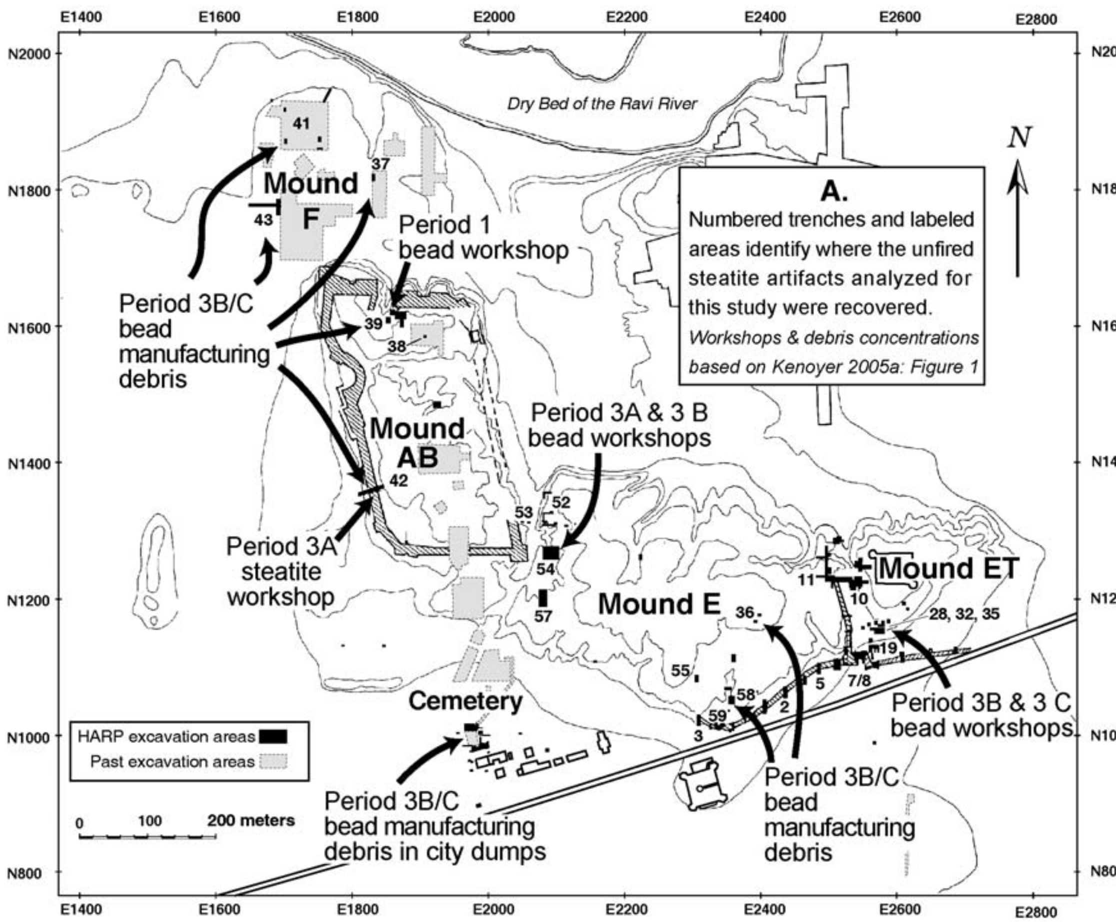
I also analyzed a small cylindrical bead made of black steatite (Figure 7.5 B). This artifact (H96/7467-658) was recovered from a disturbed deposit in Trench 39 on Mound AB that contained mix debris from Period 2 and later levels.

During the 2000 HARP field season, 177 tiny steatite bead blanks were recovered in an ashy debris layer in Trench 54 on the west side of Mound E (Meadow et al 2001: 14). They date to Period 3A and were likely dumped from one of the many workshops found in that area. It was quite exciting for me to analyze these particular artifacts as I was involved in the painstaking excavation and mapping of them. The bead blanks are composed of a steatite that is varying shades of grayish-yellow (Type B). A darker example (Figure 7.5 C) and a lighter example (Figure 7.5 D) were selected for analysis (H2000/2301-176 & 177).

Lastly, a black steatite wig (H98/8668-2) that was likely part of small composite statue (the wig sits on a display bust in Figure 7.5 E) was recovered from later Period 3C levels in Trench 43 on Mound F. This artifact is identical to ones associated with the Bactria-Margiana Archaeological Complex (BMAC) of southern Central Asia and its recovery was an important new piece of evidence for Harappan interaction with peoples from that region (Meadow 2002). A tiny spur of material protruded from an area on the interior surface of wig, which Dr. Mark Kenoyer was able to carefully remove for analysis.

In the end, 140 unfired steatite artifacts recovered from Harappa were selected for geologic provenience analysis using INAA. Contextual and macroscopic type information for all artifacts in the set is listed in Appendix 7.1. Their spatial and temporal distributions are detailed in Figure 7.6. Although no formal strategy was employed in the selection process, an effort was made to assemble a set of samples that was representative of both

Figure 7.6: Distribution of the unfired steatite artifacts from Harappa analyzed for this study.



B: Spatial and temporal distribution of the140 unfired steatite artifacts analyzed for this study.								
Mound ↓ / Period →	**1**	**2**	**3A**	**3B**	**3C**	**4/5**	**surface & disturbed**	*total*
F	*not present*	*not present*	*not present*	2	13	*none available*	*not sampled*	*15*
AB	2	17	21	11	2	2	3	*58*
E	*none available*	1	2	7	15	*none available*	12	*37*
ET	*not present*	*not present*	*not present*	1	19	*not sampled*	4	*24*
cemetery & off mound	*n/a*	*n/a*	*n/a*	*n/a*	4	*n/a*	2	*6*
total sampled	*2*	*18*	*23*	*21*	*53*	*2*	*21*	***140***
percent of total assemblage (see Figure 7.3)	1.25%	25.35%	5.13%	15.91%	3.81%	33.33%	2.68%	**4.68%**

the contexts where unfired steatite artifacts are found (which is to say all parts of the site and all of its chronological phases) and of the raw material itself (i.e., the seven main macroscopic "types"). I believe the effort was successful. Compare figures 7.3 and 7.6 B. Although the sampling of Period 2 was a bit heavy at the expense of Period 1, the temporal distribution of the set roughly mirrors that of the sub-assemblage. Likewise, the synchronic spatial distribution of the samples and the sub-assemblage correspond reasonably well with one another. In the set, there are 53 examples of Type A steatite, which is the most abundant type at the site and there are six examples of Type G, which is the rarest. The amounts of the other types fall in between, once again, much as they do in the assemblage.

Overall, the 140 unfired steatite artifacts selected for analysis represent a 4.68% sample of this material sub-assemblage at Harappa. Importantly, many of the artifacts were recovered from contexts within or adjacent to bead workshops identified by the HARP. Most of the rest, although not clearly linked to workshops, were found among heavy concentrations of bead-making debris. These associations (see Kenoyer 2005a: Figure 1 and Figure 7.6 A above) strengthen our ability to use such artifacts to investigate questions regarding the control of resources and production by residents of different areas of the site.

Steatite samples from other prehistoric sites

I was fortunate to have been able to supplement the archaeological dataset with 37 unfired (or partially fired) steatite artifacts from seven other prehistoric sites in India, Pakistan and Iran (Figure 7.7). The inclusion of these samples has provided a more holistic picture of steatite acquisition networks in the Greater Indus region as well as a glimpse into what types of steatite people were using in areas sometimes far removed from Harappa.

Figure 7.7: Unfired steatite artifacts from other sites analyzed for this study.

A. Fragments from Mohenjo-daro (MD)



B. Artifacts from Mehrgarh (MR) and Nausharo (NS)



C. Sawn steatite from an unknown site in Loralai (LOR-s1)



D. Black steatite beads from an unknown site in Loralai (LOR-s2)



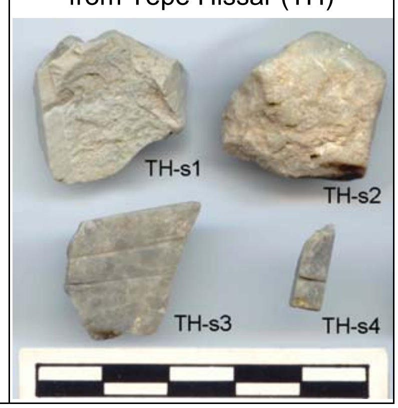
E. Steatite fragment from Nagwada (NGW-s1)



F. Two views of a broken unicorn seal from Gola Dhoro (GD-s1).



G. Sawn steatite fragments from Tepe Hissar (TH)



Fifteen unfired steatite fragments (Figure 7.7 A) from the Indus city of Mohenjo-daro in Sindh were provided by Massimo Vidale (l'Istituto Italiano per l'Africa e l'Oriente [IsIAO], Rome) and Ghulam Mustafa Shar (Department of Archaeology, Shah Abdul Latif University, Khairpur). Both scholars have conducted extensive research at that site and jointly published an ethnoarchaeological study of steatite working in Balochistan and Sindh (Vidale and Shar 1990). All samples are surface finds collected during the mapping of craft activity areas. Although from non-secure contexts, they almost assuredly date to the site's Harappa Phase occupation (probably from the latter part of that phase). Samples MD-S7 through MD-S11 (Figure 7.7 A *middle row*) were recovered among various kinds of lapidary craft debris in the "Moneer" Area (Vidale 1987a, 1990). All others come from steatite-working areas discovered on the western side of area DK-A (Vidale 1987b, 1989c).

In the research collections of the Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet, Paris, there are a numerous steatite artifacts from the Neolithic/Chalcolithic settlement of Mehrgarh and the nearby (6 km southwest of Mehrgarh) Indus Civilization town of Nausharo. The sites are located at the foot of the Bolan Pass – a major route connecting the Indus Valley to the central Balochistan highlands and beyond to the Helmand Basin. Dr. Jean-François Jarrige, who directed excavations at both sites, graciously provided me with a set of unfired steatite artifacts for this study (Figure 7.7 B). The first seven of the 13 samples from Mehrgarh are black steatite bead roughouts (MR-s1 through MR-s3) and debris fragments (MR-s4 through MR-s7) recovered from a workshop (atelier) in area MR4 that dates to the early Chalcolithic Period (Mehrgarh IIB – ca. 5000 BC) (Jarrige 1981: 99). These artifacts and

several hundred more like them from the same deposit were the subject of studies aimed at reconstructing the steatite bead manufacturing process (Vanzetti and Vidale 1994; Vidale 1995). The remaining six samples from Mehrgarh include a debris fragment (MR-s8) and several small red, green and black steatite beads or bead fragments (MR-s9 through MR-s13) from Period I levels (ca. 7000 – 5500 BC). A single broken bead (NS-s1) from Nausharo rounds out the sample set. It is composed of a bright red steatite and dates to Nausharo Period III, which is roughly equivalent to Period 3B at Harappa.

In March of 2001, I met with Mr. Syed Ghani – an Assistant-Director at the Geology Survey of Pakistan-Quetta, in order to discuss the geology of the Loralai District of northern Balochistan, which was his research area as well as his native place. At that meeting, he showed me a box containing stone artifacts given to him by the local people of that area. Among the mostly chert blades were two kinds of steatite artifacts – a red steatite fragment that had been sawed on one end (Figure 7.7 C) and a group of tiny black steatite beads (Figure 7.7 D). He said he believed the artifacts were from a mound in the Loralai Valley but he could not tell me its name or precisely where it was. Having seen many artifacts like these before, I felt fairly certain that both were from the prehistoric period. The fragment, in particular, caught my attention. Although somewhat reminiscent of Type G steatite at Harappa, the patterning and unusually deep red color of the stone appeared to me to be identical to a material used to make a number of the stamp seals at Mohenjo-daro. Compare Figure 7.7 C to, for example, the seal pictured on the cover of Asko Parpola's book *Deciphering the Indus Script* (1994). Mr. Ghani kindly allowed me to remove a small piece from the sawn fragment and select a few of the black beads for this analysis.

Dr. Kuldeep Bhan (Department of Archaeology, Maharaja Sayajirao University, Baroda) provided two samples for this study from Indus Civilization settlements located in Gujarat. The first was a piece of light-green steatite (Figure 7.7 E) removed (by Dr. Bhan) from a large chunk of unworked material (Hedge et al 1990: 193; Sonawane 1992: 165) recovered in Harappan Period levels at the site of Nagwada, which is located on the western edge of the North Gujarat Plain. The second was a sample taken directly from a unicorn stamp seal discovered at Gola Dhoro (also known Bagasra) in the northern part of the Saurashtra Peninsula (Bhan et al. 2004). The seal (Figure 7.7 F *left*), which was one of five discovered at that very small (≈ 2 ha) walled settlement, had been broken in antiquity and a zone of raw, greenish-grey steatite was exposed in its unfired interior (Figure 7.7 F *right*). Dr. Bhan was able to remove a small sliver of material from that area for analysis.

The final artifacts sampled for this study are four pieces of sawn steatite (Figure 7.7 G) collected (and again kindly provided) by Dr. Massimo Vidale from the surface of the Bronze Age site of Tepe Hissar (Schmidt 1937) in northern Iran (not shown on Figure 7.2). Numerous craft activities, including steatite working, have been documented at this site (Bulgarelli 1979; Tosi 1989), which exhibits limited evidence of long-distance contact with the Greater Indus region (Chakrabarti 1990: 7-8; Heskel 1984). Analysis of the fragments provides a way to compare Harappan steatite to raw material that was (presumably) acquired from geologic sources in that distant region (over 2000 km northwest of Harappa).

Now that I have presented the set of 177 samples (140 from Harappa and 37 from elsewhere) of archaeological steatite assembled for this provenience study, the next step is to outline and discuss the geologic sources to which they are (and are not) be compared.

Identifying potential steatite sources for Indus Tradition peoples

Dr. Mark Kenoyer has argued that "one important factor in the development and expansion of Indus trade networks is that many essential raw materials needed by the Indus cities were available in more than one locality" (Kenoyer 1998: 91). With regard to steatite – a raw material which the need for and the trade in was evidently "continuous and massive" (Vidale 2000: 58) – craftspeople and consumers at Indus cities would have quite possibly depended on having access to stone from multiple sources. Beginning with Sir Edwin Pascoe, who wrote the chapter entitled "Minerals and Metals" (Pascoe 1931) for the first Mohenjo-daro site report (Marshall 1931b), there has been a great deal of speculation by researchers about exactly where those sources might have been located (Asthana 1993: 274; Biwas 1996: 47; Fentress 1976: 306; Kenoyer 1998: 93; Lahiri 1992; Law 2002; Ratnagar 2004: 166-167; Shaikh 1987: 72; Thapar 1993: 11; Vidale 2000: 58). Some of the more recent speculation is well informed while some is merely a rehash of what Pascoe wrote 75 years ago. For this study, it was crucial to have an accurate and comprehensive knowledge of where steatite was available to Harappans in the Greater Indus region and to obtain samples for provenience analyses from as many of those sources as possible.

In this section, I first discuss the petrogenesis of steatite. This is helpful not only for understanding where deposits of this stone tend to be found but is it also necessary for evaluating the results of the geologic provenience analysis presented in the section that follows this one. I then say a brief word about the sampling of the steatite sources for this study. The bulk of this section is devoted to detailing where steatite *of the quality* that Harappans used occurs in the Greater Indus region and, importantly, where it does not.

Steatite petrogenesis

Steatite is called *soapstone* or *potstone* in the West and *zahr muhra*, *silkhari* or *ghia pattr* in South Asia. Some archaeologists (especially those working Arabia, Iran and West Asia) prefer to use the term "softstone" for steatite, chlorite, serpentine and other carvable rocks with a low Mohs hardness. This is understandable; particularly with regard to the materials just mentioned as they can closely resemble one another and, in certain geologic settings, co-occur in the same stone. However, I have avoided using the term here because it is simply too vague. Steatite is a rock composed predominantly of talc. XRD analyses (Appendix 4.1) have clearly shown that this is the variety of stone Harappans were using.

The mineral talc ($Mg_3Si_4O_{10}(OH)_2$) forms when magnesium-rich rocks are altered by low-grade stress, heat or hydrothermal action (Deer et al.1992: 330). "Talcose" rocks thus tend to occur at or near tectonic plate boundaries, in ophiolite zones (areas where plate tectonics have uplifted and emplaced large fragments of oceanic crust onto a continental landmass) or other areas where metamorphic processes have acted upon a suitable parent-rock. There are two kinds of parent-rocks suitable for the formation of talc. The first are *ultramafic* (high magnesium - low silica) igneous rocks. These include (but are not limited to) peridotites, dunites, pyroxenes and serpentinites, which are common in oceanic crust and, thus, the reason why steatite bodies sometimes develop in ophiolites. The second kind are calcareous sedimentary rocks (usually limestones but also some mudstones) that have had their calcite ($CaCO_3$) component converted to calcium magnesium carbonate ($CaMg(CO_3)_2$) in a process called *dolomitization* (Blatt 1992: 312). *Dolomite*, *dolostone*, *dolomitic limestone* and *magnesium limestone* are all terms used to refer to this type of rock.

Owing to its diverse geologic origins, steatite may contain, in addition to talc, any number of a wide variety of accessory minerals. Using XRD, Vidale and Bianchetti (1997) identified *dolomite* and *quartz* in steatite samples from Harappa (as did I – see appendices 4.1, 4.2 B and 4.2 C), *calcite* in a sample from Mehrgarh and *magnetite* and *clinochrysotile* in samples obtained from a modern craftsman. Barthélémy de Saizieu and Bouquillon (1994: 51) detected *anthophyllite* in steatite beads from Mehrgarh. Chlorite, serpentine and chromite are other accessory minerals that may be found in steatite. Vidale expressed (2000: 59) hope that XRD could be used to address questions of provenience by identifying mineralogical sub-groups within the steatite found at Indus sites and, to a certain extent, it can. Steatite containing dolomite is clearly of dolomitic origin. Magnetite is an extremely common constituent of igneous rocks (particularly serpentinezed peridotites and dunites) and, when detected, probably indicates steatite of ultramafic origin. With such knowledge one can focus on or exclude certain types of geologic formations as potential sources (e.g., there no need to go looking in ophiolites for the sources of steatite containing dolomite as an accessory mineral). However, XRD, at best, can really only take you that far. Accessory minerals are often present in amounts too low to be detected by XRD (note that only talc was detected in 20 of the 29 X-rayed samples from Harappa – Appendix 4.1).

Chemically pure talc is white. It is accessory minerals (detectable by XRD or otherwise) in the stone that provide steatite with its highly variable range of colors and patterns (recall Figure 7.4). Visual appearance could conceivably help to identify steatite artifacts from specific sources, provided that it is distinctive enough. For instance, among the modern samples that Vidale and Bianchetti analyzed (1997) was a pale green steatite

with prominent black spots. Vidale obtained this sample from a craftsman in Khairpur who himself had acquired it at the shrine of Shah Noorani in southern Balochistan (Vidale and Shar 1990). The stone actually occurs in the nearby Las Bela ophiolite (discussed below). In my experience, no other steatite with the exact same visual characteristics can be found elsewhere the Greater Indus region. It is used to make distinctive pendants and rosaries that are traded widely throughout Pakistan. Wherever I have encountered such stone in the *kabat* (portable display case) of a *johri* (professional stone seller), it was always attributed to Shah Noorani. Most steatite is not as visually distinctive as this, however. Moreover, the appearance of material within a single deposit can be highly variable. I have visited many deposits that contain stone resembling most of the macroscopic types present at Harappa. Also, the kind of parent-rock that steatite forms in does not necessarily endow it with a certain range of colors or patterns. I have collected samples from deposits of both dolomitic and ultramafic origin that, macroscopically, are indistinguishably from one another.

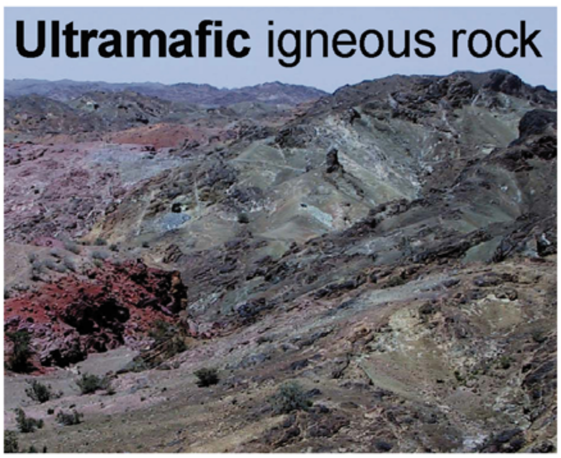
Ultimately, it is studies focusing on trace elements in steatite artifacts, rather than on mineralogy or visual appearance, that hold the most promise for determining their geologic provenience. Ultramafic rocks contain high concentrations of transition metals like chromium, cobalt and nickel (Dann 1988: 23). Truncer and others (1998) found that steatite deposits of ultramafic parentage could be differentiated using this class of elements. Dolomitic limestones have lower concentrations of transition metals and often exhibit unique rare-earth element (REE) characteristics (Miura and Kawabe 2000). This may allow dolomitic steatite deposits to be differentiated from ultramafic ones and from one another.

Figure 7.8 is a graphical summary of the main points of this section.

Figure 7.8

Steatite is a rock
composed primarily of the mineral
talc (hydrous magnesium silicate).

It may form in either ...



or



Muslimbagh ophiolite sequence

Khyber Dolomite

The result can be ...



visually
identical
steatite



Urgasai Nasir (ZUN) steatite

Prang Dera (LKPD) steatite

... with very **different trace element characteristics**
that reflect their respective parent-rock formations.

Sampling geologic sources

The geologic literature for South Asia contains references to hundreds of steatite deposits in the highlands adjoining the Indus Basin (in reality, of course, there are likely thousands). Obtaining a reasonable sample of the range of sources that were potentially available to Harappans may seem like an impossible task because of this. However, steatite in South Asia is unevenly distributed. The lion's shares of reported occurrences are in Rajasthan, in particular, southern Rajasthan. There are only, perhaps, four dozen or so *recorded* deposits elsewhere in the Greater Indus region. My regional sampling strategy was, thus, fairly straightforward – collect samples from as many recorded deposits in Pakistan, northern India and Gujarat as I could possibly to get to (and hopefully locate some unrecorded ones in the process) and then selectively sample occurrences in Rajasthan.

The sampling of an individual steatite occurrence typically involved walking along a zone of mineralization or across the breadth of a quarry and collecting the full range of the macroscopic types of *Harappan-quality* material present there. Steatite used by Harappans was, regardless of its color, patterning or mineralogy, almost always a very compact, physically homogenous stone. Materials from many of the deposits reported throughout the Greater Indus region, although perfectly suitable for modern industrial uses (Chatterjee 1978), would not have passed muster with Harappan seal-carvers or bead-makers because they were too impure (making them difficult to carve and saw) and/or their structure was too foliated (causing them to flake or split during manufacture or use). Not all of the nearly 60 locations I visited for this study contained Harappan-quality steatite. In the end, suitable samples from 37 different sources (18 in Rajasthan and 19 from elsewhere) were obtained.

Steatite occurrences of the Greater Indus region

Before we begin the overview of steatite occurrences, please refer to the map of the Greater Indus region found near the start of this chapter (Figure 7.2). Marked on it are the geologic sources and archaeological sites that are discussed in this section. Labeled ellipses indicate areas where multiple deposits were sampled. Detail maps (figures 7.9 A, 7.10 A and 7.12) for those areas are provided throughout this section. Note that different types of symbols mark the sources and sites shown on the various figures. These maps and the symbols on them serve as the keys for the scatterplots used in next section of this chapter. On some maps deposits are labeled with a two-to-four letter source code. The full source names for those codes is provided in text but can also be found in Appendix 7.2, along with other locational (region, district/agency, geographic coordinates) and geologic (parent-rock type) information pertaining to the steatite sources sampled for this study. Marked with blue circles and/or labeled in blue are locations or regions that I discuss, but for which steatite samples were not analyzed. The reason for this was either 1) I was unable to visit the area; 2) the steatite at the location was of a very low-grade and not at all of the quality that Harappans used; or 3) steatite did not actually occur there as reported.

Refer again to Figure 7.2. We begin this overview in southern Balochistan and then move clockwise around the highlands surrounding the Indus Basin – first going through northern Balochistan and then on to the NWFP and Pakistan's Northern Areas. We then turn southeast to follow the Himalayas for 600 km. After that that point we jump across the Gangetic Plain to the Aravalli Range of Rajasthan and follow it from the northern to the southern part of that state. Our tour of steatite occurrences will end in Gujarat.

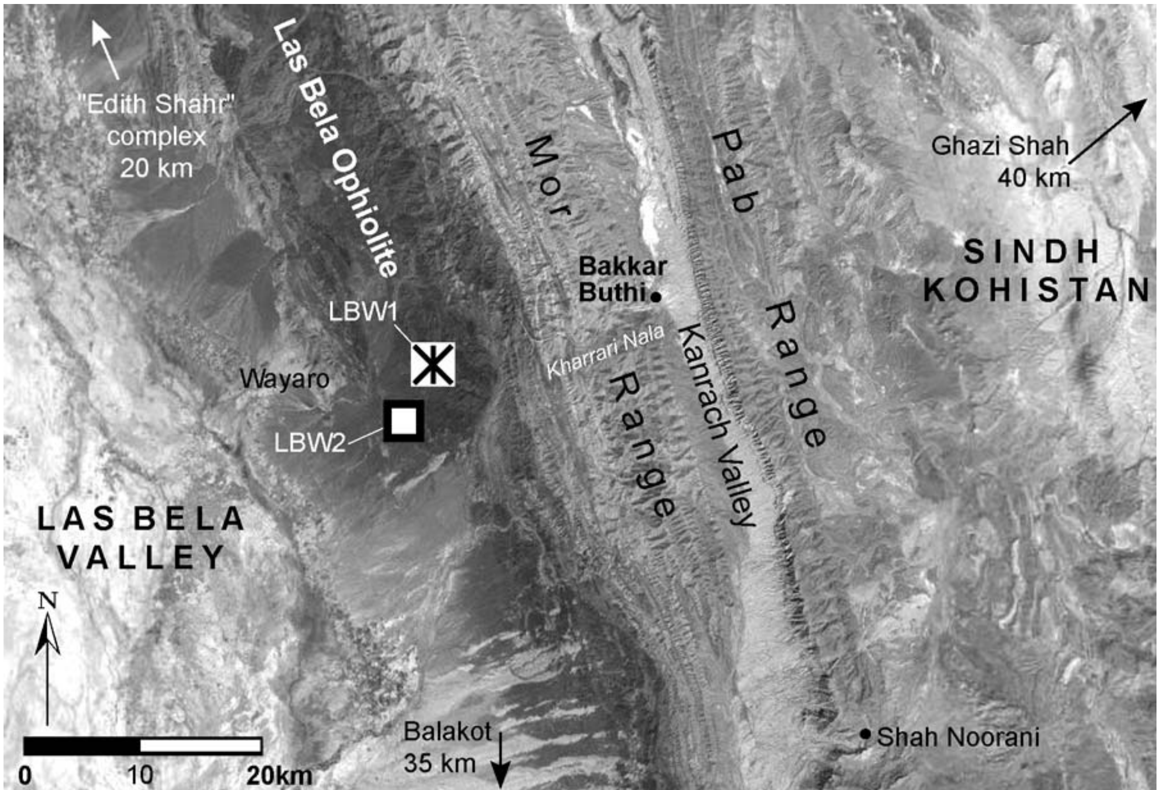
Steatite occurrences in Balochistan

Las Bela District

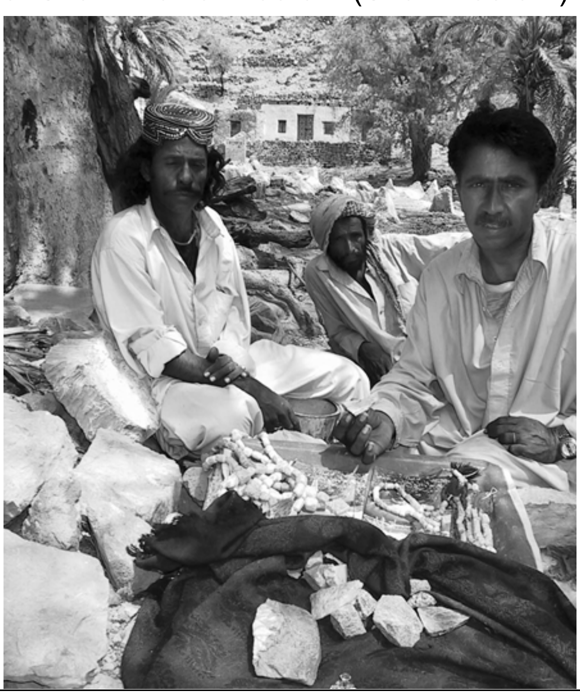
Steatite occurs at a few places in the Las Bela District of southeastern Balochistan. Prior to sampling those deposits, I had not encountered any reference to them in either the geologic or historical literature. I only located them because I wished to visit the shrine of the Sufi saint Shah Bilawal Noorani (or just Shah Noorani), which I had first learned about in Vidale and Shar's study (1990) of traditional soapstone crafts in Sindh. According to a johri/steatite-carver they interviewed named Ashiq Hussain, the shrine was the place where he had learned his craft and to where he traveled annually to attend the *mela* (festival) for the saint. It was also where he replenished his steatite stocks as it was in the "land of zahr muhra" (ibid.). Steatite could be acquired from local Mengal tribesmen who transported the stone to the shrine from sources that were a two or three-day walk away.

In Vidale and Shar's 1990 study, Shah Noorani is described as being in the Makran District, near the modern town of Turbat and the prehistoric sites of Shahi Tump and Miri Qalat (Besenval 2005). However, I could not locate it on maps or in the gazetteer for that district. Moreover, there were no geological formations in the region that could have hosted steatite deposits (there are ophiolites in the Iranian Makran, however). I learned from a johri in Karachi that, in actuality, Shah Noorani lies some 400 km to the east of the Turbat area in the Las Bela District near the Balochistan-Sindh border (Figure 7.9 A). Mention is made of the shrine in the *Gazetteer of Las Bela* (1907: 38). You can catch a bus from Lee Market in Karachi and be there in six hours. I visited Shah Noorani in May of 2001 and met with the johri/steatite-carvers there (Figure 7.9 B) who told me that the actual

Figure 7.9: **A**. Las Bela Ophiolite, Las Bela District, Balochistan



B. Johris/steatite-carvers at the shrine of Shah Bilawal Noorani (Shah Noorani)



C. Duddo steatite mine (LBW1)



sources of zahr muhra were in the Wayaro area, about 45 km to the northwest. This placed them squarely in the middle of the Las Bela ophiolite – a geologic formation that could undoubtedly host steatite deposits (as well as the chlorite and serpentine that the Shah Noorani johris are also known for carving and selling).

Later the same month, I visited the Wayaro area with Khawar Akhbar of the Geological Survey of Pakistan–Karachi. With the help of a local man we located and sampled two active mines at locations called Duddo (LBW1) and Thaddi (LBW2), which were about 5 km apart. Throughout the area there were pits and shear zones from which steatite appeared to have been removed long before. We found no artifacts to provide us with an indication of when exactly that might have been, however, and our guide did not know of any mounds or other evidence of old settlements in the immediate area. This came as no surprise. Ophiolite zones are notorious for being lifeless, moon-like landscapes (Dann 1988: xi) and the area around the Wayaro deposits was no different (Figure 7.9 C).

Prehistoric settlements were not a great distance away, however, in any direction. Bakkar Buthi, which was occupied by Indus Civilization peoples for a period of time (Franke-Vogt et al. 2000), lies less than 20 km away on the other side of the Mor Range in the central Kanrach Valley. The Wayaro steatite sources could easily be reached from there via Kharrari Nala, which transects the range at that point. The site of Balakot, which has Early Harappan and Harappan phase occupations (Dales 1974), is situated some 60 km due south of the Wayaro area. All across southeastern Balochistan and into Sindh Kohistan sites belonging to the Early Harappan Nal and later Kulli phases are found (Fairservis 1975: 185-216). The so-called "Edith-Shahr" complex (ibid.) is just to the north at the

head of the Las Bela Valley. On the other side of the mountains of Sindh Kohistan lie Amri (Casal 1961), Ghazi Shah (Flam 1993a) and other Early Harappan / Harappan Period sites.

My reason for highlighting the proximity of other prehistoric sites to the Wayaro deposits was to emphasize their importance as *potential* sources of steatite for Early Harappan and Harappan phase peoples. In simple terms of physical distance between a known Indus Civilization site and a deposit of high-quality (or any quality for that matter) steatite there are no closer sources. Moreover, I show in Chapter 12 that lead ore at Harappa and Mohenjo-daro may have been acquired from deposits of that metal in the Kanrach Valley. For consumers in Sindh in particular, the Wayaro area of southern Balochistan *could* have been a very important source of steatite. Deposits there, although fewer in number, are over three times as close to Mohenjo-daro as those in Rajasthan, which has long been argued (Pascoe 1931: 679) to have been a major source of steatite for residents of that site. Most importantly, Early Harappans and Harappans were indisputably present in southern Balochistan and so the interaction networks through which steatite could have been brought to the Indus Valley were in place. Evidence that Harappans interacted with the peoples of Rajasthan, although it exists (Misra 1995, 1997), is much more tenuous.

One thing regarding these deposits gave me pause, however. I have only seen an artifact made from the distinctive type of green steatite with black spots at a single prehistoric site – Balakot, which is not surprising as it is relatively close by. A small unfired bead from that site composed of this type of steatite is in collections of the Department of Archaeology and Museum’s Excavation Branch in Karachi. Nothing like it, however, is in the unfired steatite assemblage at Harappa or among the unfired artifacts

from other sites that I have examined or seen photographs of. True, there are other macroscopic types of steatite at the Wayaro deposits. Perhaps Harappans were mining those instead. Or, perhaps, every single piece of this kind of steatite at Indus sites has been heat-treated, thus obscuring the original the appearance of stone. I have doubts about the latter possibility, however. Whatever the case actually is, statements like Louis Flam's (1981: 168) – that the source of steatite for the Early Harappan peoples of southern Sindh (Amri Phase) "can be supposed to have been southeastern Iran," are definitely now untenable.

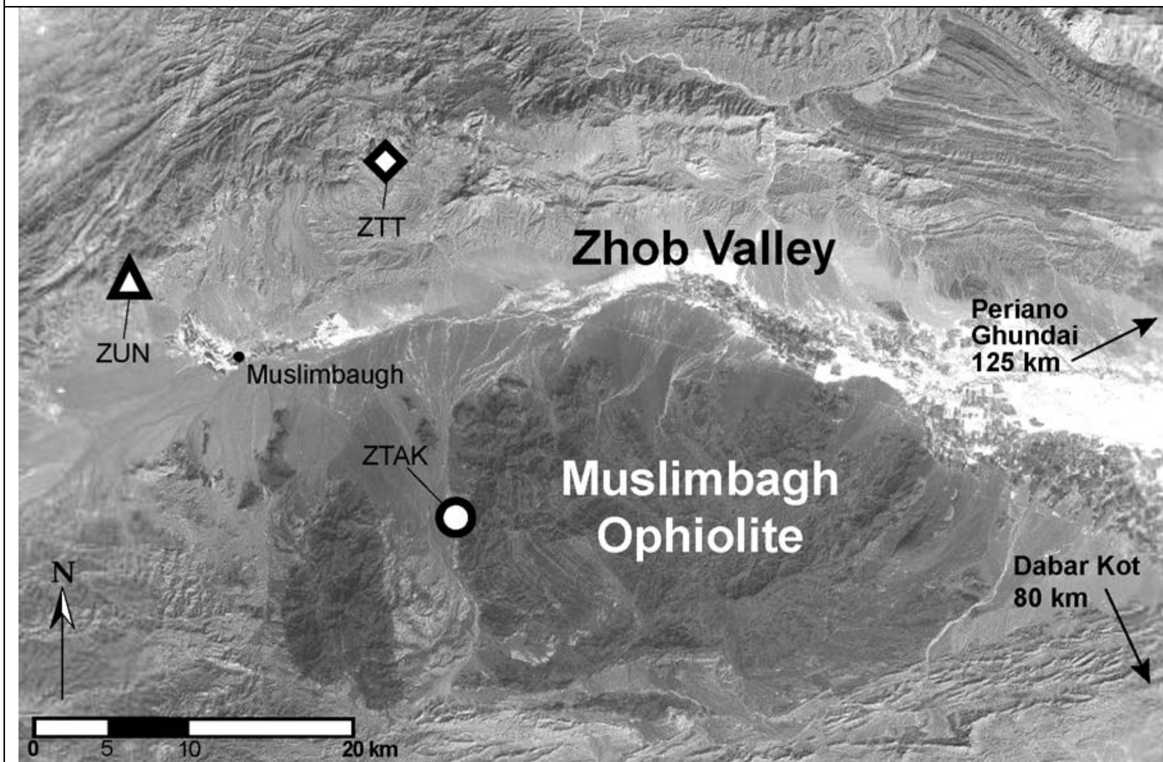
Kalat District

Moving northward now to the Kalat District of central Balochistan, Tariq and others reported (1998: 16) a 7 to 12 cm thick vein of light-grey soapstone in the lower shale member of the Shirinab Formation near the village of Chuttock. At just over 90 km to the west-northwest, this is the closest reported steatite occurrence to the sites of Mehrgarh and Nausharo. Unfortunately, I only learned of this occurrence after my Balochistan fieldwork was completed and so no samples from it could be included in this study.

Zhob District

Continuing on to northern Balochistan, Ahmad noted (1969: Figure 30, #9) soapstone in the southwest part of the Zhob District but provided no further details on the occurrence(s). Fortunately for me, the region was the research area of Dr. Khalid Mahmood of Center of Excellence in Mineralogy, University of Balochistan-Quetta. He was able to lead me to and assist me in the sampling of high-quality steatite deposits at three locations in the Muslimbagh ophiolite (Figure 7.10 A). The occurrence at Takhahen (ZTAK) in the main body of the ophiolite provides a good illustration of how, whenever possible, I

Figure 7.10: **A**. Muslimbagh Ophiolite, southern Zhob District, Balochistan



B. Direction of talc mineralization near Takhahen (ZTAK) – looking north



C. Points sampled along a 2km zone of steatite mineralization near Takhahen



approached sample collection. The zone of talc materialization there runs intermittently along a 2-km long north-south strike (Figure 7.10 B). Samples (n ≈ 50 total) were acquired from three points along the zone where the best quality material could be found (Figure 7.10 C, points 1, 2 & 3). The zone was treated a single deposit as it essentially occurs in the same block of *harzburgite* (a peridotitic rock). Samples were also collected in this way from fragments of ophiolitic rock containing steatite on the opposite side of the Zhob Valley, to the north of Muslimbagh town at Urgasai Nasir (ZUN) and Takhahen (ZTT).

The Muslimbagh ophiolite steatite deposits would have been the ones most accessible (≈ 80 to 120 km distant) to the prehistoric peoples of the Loralai District. For this reason, they are the best candidates for the sources of the sawn steatite and black beads (Figure 7.7 C & D) in archaeological sample set said to be from a mound in that area. I have represented those two samples on Figure 7.2 using a red plus ("+" for the sawn fragment) and a red circle ("O" for the beads). Steatite from the Muslimbagh ophiolite could have been accessible to residents of Harappa during the urban phase as there was a clear Indus Civilization presence in the Loralai region at the sites of Dabar Kot and nearby Duki Mound (Fairservis 1975: 149).

From Muslimbaugh, the Zhob Valley arcs north-northeast and terminates near the border with the NWFP. Soapstone or talc is reported at several locations around this region (Heron and Crookshank 1954: 138; Pithawalla 1952: 202), which evidently was a key zone of interaction between the northern Balochistan highlands and the Indus Valley during the first half of the third millennium BC. At the northern end of the Zhob Valley sits the site of Periano Ghundai. A strong Early Harappan Kot Dijian presence is documented there

(Mughal 1970: 217-221) alongside the site's highland "Zhob culture" material assemblage. Clusters of Early Harappan and Harappan Period sites (Dani 1971; Durrani 1988; Khan et al. 2000; Mughal et al. 1996) are found where the rivers draining northern Balochistan meet the Gomal Plain / Derajat region of the western Indus Valley. Ceramic parallels as well as finds of "Zhob mother goddess" figurines indicate that peoples from at least one of these plains sites – Dhera, had very close ties with the adjacent highlands (Siddique 1996).

Pockets of ultramafic rock dominated by the Zhob ophiolite are found in the northern Zhob region (all within about 50 km of Periano Ghundai) and "veins of up to a foot or so in thickness of white steatite" have been reported to occur in them (Heron and Crookshank 1954: 138). I visited two reported locations with Dr. Khalid Mahmood. An afternoon of searching the area "east of the 22nd milestone on the Ft. Sandeman-Gul Kach road" (ibid.), which is in the main body of the Zhob ophiolite, yielded only serpentine and chlorite. The local people around had no knowledge of any soapstone occurrence or any former mining operation. At Wulgai Oba (ibid.), we found only thin seams of very low grade talcose stone in what turned out to be dolomitic slates rather than ultramafic rock. We forewent a visit to a third reported soapstone occurrence on the road to Shinghar as the deposit was said to consist of only small talc "veins, which have been worked by local inhabitants for whitewash paint" (Huntington Survey Corporation 1960: 500).

It is very possible that there are occurrences of talcose stone in northern Zhob that Dr. Mahmood and I failed to locate (particularly in the Zhob ophiolite) during our limited period of fieldwork in that region. However, from what we observed it appears likely that there are no occurrences of Harappan-quality steatite in this region.

Steatite occurrences in the NWFP, FATA and Northern Areas

Kurram Agency

Beds of very high quality steatite occur within siliceous dolomite in the Safed Koh Range, which forms the Kurram Agency's northern border with Afghanistan. Mian Sayed Badshah of the Federally Administered Tribal Areas (FATA) Development Corporation (FATADC) organized a sampling expedition to this area for me in August of 2001. The deposit sampled (source code PD) lies just over 20 km northwest of Parachinar town at an elevation of 3000 meters in the Daradar Valley – an offshoot of the Kurram Valley on the southern flank of the Safed Koh (Badshah 1983; Bender 1995b: 273). A larger, slightly higher deposit along Kharwala Nala in the western part of the range (Meissner 1975: 18; Ahmad 1969: 155) unfortunately could not be visited because of security concerns.

The elevation and steep terrain associated with the Safed Koh steatite deposits has limited exploitation of them in modern times. Whether or not the same would have been true during the Indus period is unknown. It is reasonable to believe, however, that Harappans might have had access to the Safed Koh and its resources. There is the ever present issue of "how did Harappans get to and from Shortughaï in northern Afghanistan?" Passage through the Kurram Valley offers the most direct route from the Punjab to central Afghanistan and, from there, to the north. Its use as a thoroughfare for caravans and invading armies rivals and, perhaps, even surpasses that of the more famous Khyber Pass to the north (Markham 1879: 47-50). Although no prehistoric sites have been discovered in the Kurram Valley itself, the Kurram River passes the south flank of the Safed Koh Range and flows southeast into the Bannu Basin, where there was a strong Kot Dijian presence

that was evidently sustained through a "Late" Kot Dijian phase concurrent with the Harappan Period (Khan et al. 1988, 1991a, 2002a).

Khyber Agency

Ahmad reported (1969: 154) that steatite occurs in dolomite around the Landi Kotal area of the Khyber Agency but did not provide a deposit name or an exact location. After a visit to the agency headquarters in Landi Kotal town in December of 2000, I learned that the stone could be found at Prang Dera, approximately 10 km to the south-southwest. I was provided with guards and guide and managed to visit the deposit (source code LKPD), which turned out to contain material of superb quality. I was told by local people that there were a handful disused mines in the area but was unable to visit any of them. The proximity of Prang Dera to the famous Khyber Pass at least opens the possibility that steatite from this source may have been accessible Harappans traveling to and from Shortughaï, that is, if it was one of the routes they took.

Also in the Khyber Agency, talc in dolomite occurs on the western side of the Peshawar Valley, 6 km north of the Khyber Pass entrance at Jamrud (Abbas et al. 1967). I visited this deposit in November of 2000 and found the steatite there to be foliated and filled with inclusions. Higher-grade stone could have been present in the past (the deposit has reportedly been worked for 50-plus years). However, the material described in a report by Abbas and others (1967) thirty years ago was also of mediocre quality.

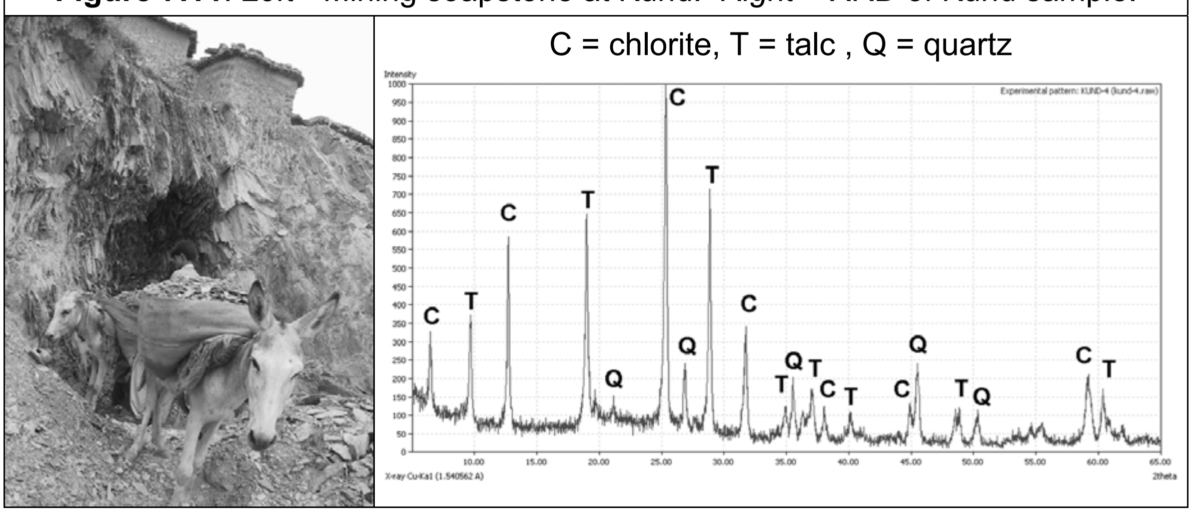
Peshawar District

In the southeast part of the Peshawar District, soapstone in metamorphosed Attock slate is found at Kund and nearby Kath Miani (Heron and Crookshank 1954: 138-139). At

the outset of this project, I considered these deposits to be potentially very important because of their location at the entrance of the Peshawar Valley near the fording point of the Indus River at Attock, as well as because of their relative proximity (≈ 60 km) to the Early Harappan sites of Sarai Khola and Hathial (Figure 7.12 A). However, after having visited the Kund deposit (Figure 7.11 *left*) and analyzing samples collected there, I am of the opinion that Harappans probably did not acquire any steatite from these occurrences. Below, I go into slightly greater detail in my discussion of the Kund-Kath Miani deposits in order to provide an illustration of exactly how I made judgments as to what constituted sources of "Harappan-quality" steatite. Such judgments ultimately determined which sources were selected to be compared to steatite artifacts in geologic provenience analyses.

To begin with (and most importantly), Kund soapstone is heavily foliated and easily fractures into platy pieces. Harappan craftspeople would have found it to be completely unsuitable for sawing or carving. Secondly, XRD analysis (Figure 7.11 *right*) indicates that Kund soapstone is a very chlorite-rich rock with quartz impurities. No chlorite phases

Figure 7.11: *Left* - Mining soapstone at Kund. *Right* – XRD of Kund sample.



have ever been detected in any of the raw steatite artifacts analyzed from Harappa. These observations are backed up by a previous study of Kund soapstone by Qaiser and others (1980) who also described eight slately and friable samples, most of which had major chlorite phases and significant other impurities. Although I did not sample the nearby occurrence at Kath Miani, Heron and Crookshank's description (1954: 139) of the material there – "impure soapstone mixed with shale debris," suggests it is of the same low quality.

There is, of course, always the possibility that, in former times, a higher-quality steatite occurred at the Kund / Kath Miani deposits, but that it has since been mined out. However, given the foliated nature of the original parent-rock (Attock Precambrian slates) I doubt that is true. Vidale and Bianchetti analyzed (1997: 949) a block of "whitish steatite" that was purchased in Khairpur, Sindh but which was said to have been mined near Attock. XRD of that sample showed it to be pure talc. I highly doubt that that it could have originated in the Kund / Kath Miani deposits. It probably came from one of the other sources in the general region like those in the Hazara District or the Mohmand Agency, both of which are around 75 km away from the Attock area.

Mohmand Agency

In the Mohmand Agency, steatite occurs in the western part of the Sakhakot-Qila ophiolite (Rafiq 1984: 58) located on the northwest margin of the Peshawar Valley. Good quality material was located during an August 2001 collection trip to that formation with Dr. Irshad Ahmed of the Center of Excellence in Geology, University of Peshawar. Samples were taken around Kot Mazarai (source codes Kot and Kot (MP)), which happens to be in the same vicinity as an important source of vesuvianite-grossular (Chapter 9).

Chitral District

In the Shi Shi Valley – an off-shoot of the Chitral Valley in the southern Chitral District, good quality steatite occurs in the Drosh ophiolite near the village of Tar (Calkins 1981: 9). Samples were collected from this location (source code CHT) in July of 2000. Although this source is admittedly far removed from the Indus Valley, it should be noted that one of the important routes to the lapis lazuli mines in the Badakhshan District of northern Afghanistan passes through the Chitral Valley.

Northern Areas

Like Chitral, Pakistan's Northern Areas may seem as if it is too remote to have figured significantly into Harappan steatite acquisition networks. However, major routes connecting South Asia to Central Asia traverse this region and ancient petroglyphs found alongside these routes provide evidence for the long history of their use (Jettmar 1991). Steatite occurrences in the region include those in the Chalt area in the Gilgit District (Bender 1995b: 273) and several in the Shyok Valley of the Skardu District (Kazmi and Jan 1997: 481). Superb quality steatite from the Ishkoman region near the Afghanistan border can be seen in the Geological Survey of Pakistan's Museum collection in Quetta (Case 22).

Swat District

A major tectonic boundary (the Main Mantle Thrust) passes along the length of the lower Swat Valley and zones of talcose rock are found all along it (Di Florio et al. 1993). I examined several locations in the valley itself but failed identify any occurrence of artifact quality steatite (admittedly though, my sampling excursions there were brief and spotty). Excellent steatite does occur, however, in the eastern part of the Swat District (outside of

the Swat Valley proper) within the dolomitic sequences of the Derai and Juragh areas (Ghani et al. 1994; Kazmi and Jan 1997: 312, 482). One deposit (source code BESH) in this zone, which I sampled with Dr. Mark Kenoyer in May of 2000, lies just 7 km from the Indus River near the town of Besham. The steatite at this location is of excellent quality.

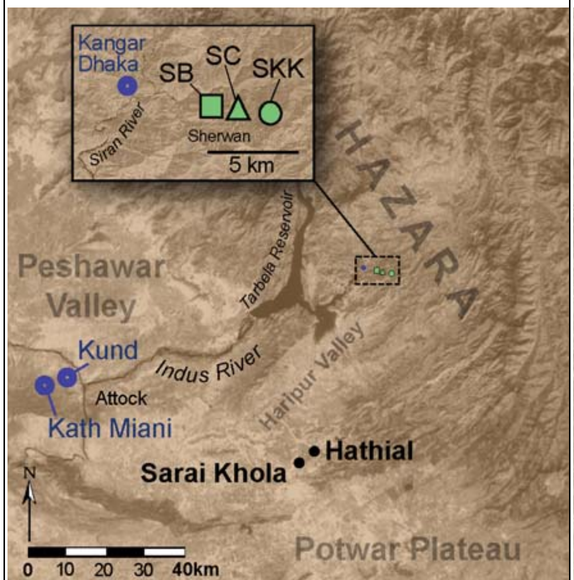
Hazara District

The most extensive steatite deposits in Pakistan are found in the Sherwan area of the Hazara District, NWFP (Figure 7.12 A) (Shah 1977: 199). The deposits occur in the dolomite sequence of the Precambrian Abbottabad Formation and extend intermittently across a zone over 16 km long and 2 km wide (Ali et al. 1964: 29-34; Bender 1995b: 273; Calkins et al 1973). As the chapter continues, I frequently refer to these occurrences as the "Sherwan zone." I visited this zone with Dr. Syed Baqri of the Pakistan Museum of Natural History in August of 2000. We conducted sampling around three locations where some of the largest deposits occurred – Bandi (source code SB), Chelethar (SC) and Khanda Khu (SKK). Excellent quality material was available at each of these locations and numerous old pits and shafts were observed, especially around Khanda Khu. There are several important occurrences in the Sherwan zone that time did not permit us to sample. A deposit at Khangar Dhaka, which separated from the main body of occurrences by the Siran River, is said to contain the highest quality material in the area (Ali et al. 1964: 34).

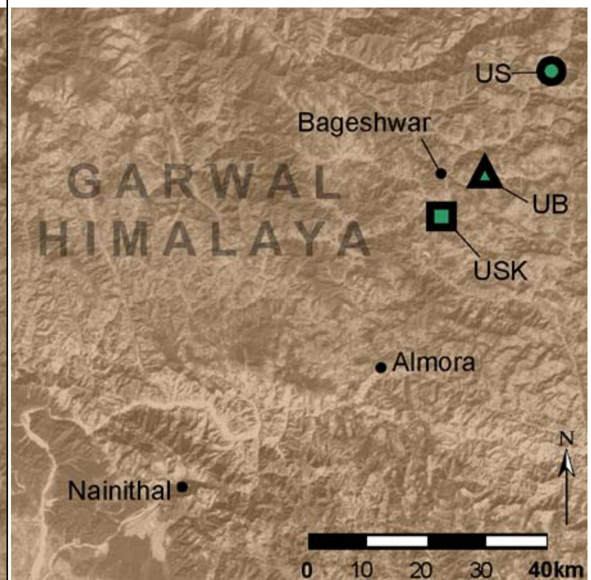
The Sherwan deposits lie 50 to 60 km north-northwest of the Kot Dijian sites of Hathial and Sarai Khola (Figure 7.12 A). People from those sites could have easily reached these sources by traveling up the Haripur Valley to the Siran River Valley (now partially flooded by the Tarbela Reservoir), which transects the zone along which they occur.

Figure 7.12: Details of regions where multiple steatite deposits were sampled.

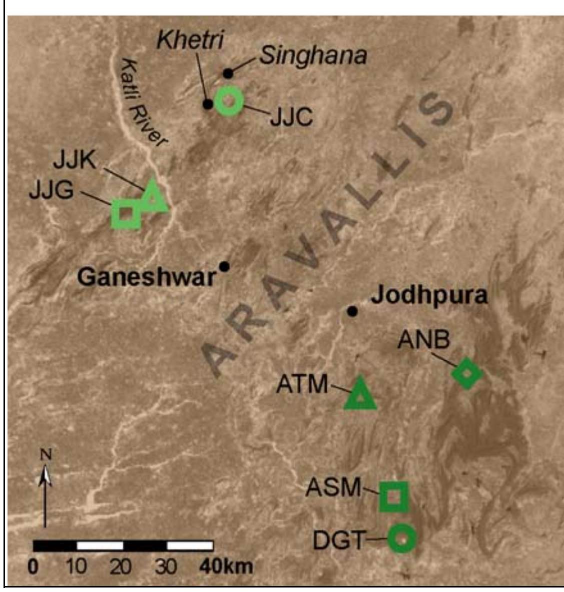
A. Sampled steatite deposits of the Hazara District, NWFP, Pakistan.



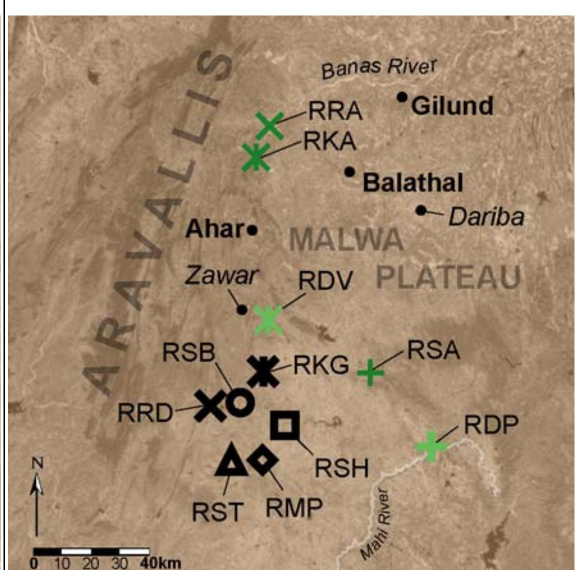
B. Sampled steatite deposits of the Bageshwar District, Uttaranchal, India.



C. Sampled steatite deposits of the Jhunjhunu, Alwar and Dausa districts, northern Rajasthan, India.



D. Sampled steatite deposits of the Rajsamand, Udaipur and Dungapur districts, southern Rajasthan, India.



Steatite occurrences in the Himalayas

Jammu and Kashmir

The steatite occurrences of Jammu and Kashmir take on a special significance in light of the clear evidence at the site of Burzahom for some form of interaction between the ancient peoples of the Kashmir Valley and those of the Indus Valley during the Early Harappan period (Saar 1992). There are a numerous routes into and out of the Vale of Kashmir that would have passed near to many of the deposits discussed in this sub-section.

Ali (1959: 10) reported an occurrence of soapstone at Chilhana Da Dana in the Muzaffarabad District but provided no details regarding it. In the Kotli District, soapstone deposits in dolomitic rock (at Palana and Nawal) are said to be "generally impure" (Ahmad 1981: 25). In the Zanskar area of Ladakh, "pockets of talc" are reported in ultramafic rock (Varadan 1977: 63). The descriptions of steatite at Nagri and, especially, at Chinchora in the Doda District give the impression that good quality material might be found at those locations (Indian Bureau of Mines 1992: 109).

In terms of this study, perhaps the most important steatite deposits in the entire Jammu and Kashmir region are those occurring in the southern part of the Great Limestone Formation in the Udhampur District (Chatterjee 1964: 436). The Early Harappan and Harappan Period foothills settlement of Manda (Joshi and Bala 1982) lies just 25 km to the southwest. Later, in Chapter 12, I present evidence showing that much of the raw lead ore found at Harappa quite possibly came from occurrences in the Great Limestone Formation. "Talc in compact form" is reported at four different locations in that formation – Kunian, Kashikaria, Nangal and Puran Daruhur (Indian Bureau of Mines 1992: 109). All are either

adjacent to or in the vicinity of Vaishno Devi – the highly revered mountain-top shrine that is today one of India's major pilgrimage places. High security at the shrine and in the hills around it prevented me from reaching the sources. Fortunately, with the help of Ajay Kumal of the Geological Survey of India's office in Jammu, I was able to locate and sample another steatite deposit in the Great Limestone Formation at a place called Painthal (source code JAMPT), which is on a ridge-top five kilometers due east of Vaishno Devi.

Himachal Pradesh

Only two occurrences of steatite have been reported in all of Himachal Pradesh – one near Asrang in the Kinnaur District and another at Nahan in the Sirmaur District (Chatterjee 1964: 436; Indian Bureau of Mines 1992: 109; Geological Survey of India 1989a: 52). The Asrang deposit, although remote, was easy to locate. However, I did not end up analyzing any of the samples collected there for this provenience study because the material I found was too soft, friable and impure to be Harappan-quality steatite.

"Good quality steatite deposits are reported nearby Nahan" (Indian Bureau of Mines 1992: 109) but when I traveled to that area in June 2003 I failed to locate any sign of them or any local person around who knew of them. I visited the Geological Survey of India's office in Chandigarh and met with N.L. Sharma and his colleagues, some of whom do research around Nahan. None of them had any knowledge of steatite or, for that matter, any kind of talcose stone in the area. Gypsum deposits and mining operations are found in southeast Himachal Pradesh around Nahan, however. The gentlemen from the GSI suggested that what was reported as steatite may have actually been that mineral. So at this point, I have to consider the report of steatite in the Nahan area to be unsubstantiated.

Uttaranchal

In contrast to Himachal Pradesh, Uttaranchal (formerly part of Uttar Pradesh) is a steatite-rich state (Chatterjee 1964: 443; Dalela 1995; Indian Bureau of Mines 1992: 161-167; Valdiya 1980: 256-257). Sources in this region, although located in highly mountainous and often difficult to reach areas, are important because they would have been among the closest to Harappan and Late Harappan peoples living on the Gangetic Plain.

I was unable to reach an occurrence of reportedly high-grade material in ultramafic rock at Kandyal Gaon (Pandey 1967) in the central part of the Uttaranchal due to a rock-slide related road closure. However, in June of 2003 I did manage to collect samples of good-quality soapstone of dolomitic origin from three occurrences in the Bageshwar District (formerly part of the Almora District) around Bageshwar town (Bhattacharya 1980; Indian Bureau of Mines 1992: 161-164; Ray et al. 1977). The first were taken from Saling mine (source code US) in the Sarju Valley north of Bageshwar; the second from along a five kilometer zone of talc mineralization that transects two valleys that extend to the west of the town (UB); and the third from an abandoned steatite mine to the south of the town called Shisha Khani (USK), which happens to be nearby a lead mine (of the same name) that I will be examining in Chapter 12.

Additional steatite occurrences can be found to the north of the Bageshwar District at high elevations in the Chamoli District (Rao and Pati 1981) and to the west in the Pithoragarh District near the border with Nepal (Bhattacharya et al. 1982). However, I decided to end sampling in the Bageshwar area for reasons of time and because I felt it (arguably) constituted the northeastern margin of the Greater Indus region.

Steatite occurrences in Rajasthan

Sir Edwin Pascoe (1931: 679) singled out the Indian state of Rajasthan (or "Rajputana" as it was called prior to 1947) as the most likely source area for the raw material used to make the steatite artifacts excavated at the site of Mohenjo-daro. Most of the other researchers (cited previously) who have weighed in on the subject of steatite acquisition by Indus Civilization peoples have either concurred or at least ranked the region high on the list of potential source areas. There is, of course, a very good reason for this. With all due respect to Ashiq Hussain and to the johris of Shah Noorani, if there is truly a "land of zahr muhra" it is Rajasthan. Steatite occurs in nine well-defined belts that run through 16 of that state's districts (Gahlot and Shukla 2000: 113) and, as of about a decade ago, there were 335 official mining leases there (Rajasthan Mineral Bulletin 1997b: 17). There are likely as many or more unofficially worked deposits and innumerable occurrences that are today considered too small to be commercially viable (*personal observations*).

Even though I devoted a large portion my available resources to the analysis of samples from this very rich potential source area (over one third of all the geologic samples analyzed came from deposits in Rajasthan), it simply would have been impossible to adequately assess steatite occurrences in all parts of the Rajasthan. So instead, I focused on obtaining samples from deposits in steatite belts situated in the northern and southern parts of the Aravalli Range, as these are the areas adjacent to regions where there were Harappan settlements (i.e, Gujarat in the south and Haryana in the north) as well as where there were well-known Chalcolithic cultures that Harappans may have interacted with (the Ahar-Banas complex of southern Rajasthan and the Ganeshwar-Jodhpura complex of northern

Rajasthan). Multiple sampling trips were made between 2001 and 2003. For many of these I was joined by Kishore Raghubans – a PhD student in the Department of Archaeology, Maharaja Sayajirao University, Baroda who was conducting research on the Ganeshwar-Jodhpura complex of northern Rajasthan. On Figure 7.2, the six districts of Rajasthan where sampling took place are marked with labeled ellipses. The ten remaining districts where steatite also occurs in the state (but which remain to be sampled) are labeled in blue.

Northern Rajasthan

During the third millennium BC, peoples of the non-urbanized Chalcolithic Ganeshwar-Jodhpura society inhabited areas in and around the northern part of the Aravalli Mountain Range (Agrawala and Kumar 1982; Rizvi 2007). Harappan acquisition of steatite from occurrences in this region (Figure 7.12 C) would have necessitated interaction with them. The deposits discussed in this sub-section lie between 140 and 240 km south of the Indus Civilization city of Rakhigarhi in Haryana.

Jhunjhunu District

The Indian Bureau of Mines lists (1992: 142) only three deposits of steatite in the Jhunjhunu District – at Chirani-ki-Dhani (JJC), Gurda (JJG) and Kho (JJK), all of which occur in "dolomite country rocks" (ibid.). All three deposits were visited and, even though it was not abundant at any of them, samples of Harappan-quality material were acquired. Importantly, these deposits lie within what constitutes the northern part of the Khetri Copper Belt (Raghunandan 1975). If the Khetri belt was one of the major copper sources for Indus Civilization peoples as many researchers have proposed (see Chapter 12 for a full discussion), then steatite may have been a resource that was acquired from this area at the

same time. Note that the occurrence at Chirani-ki-Dhani is located less than 10 km from both Khetri itself and the enormous copper smelting slag heaps at Singhana.

Alwar and Dausa districts

In the northeastern part of the Aravalli Range, steatite is reported at a few dozen places in the dolomitic limestone of the Riaolo Formation (Gahlot and Shukla 2000; Indian Bureau of Mines 1992; Rajasthan Mineral Bulletin 1997b). In the Alwar District, samples for this study were taken at Nangalhari-Bairaswas (ANB), Teori (ATM) and Samra (ASM). Like the deposits of the Jhunjhunu District, Harappan-quality stone was present but not abundant. Slightly farther to the south in the Dausa District (formerly part of the Jaipur District), the situation was very different, however. The huge open pit mine at Degota (DGT) is largest in Rajasthan and produces some of the highest grade soapstone in India. In fact, much of the stone that is being taken out of the mine is too good. That is, it was massive and compact (and would have carved beautifully) and pure white. <u>None</u> of the archaeological examples of raw steatite that I have ever seen have been pure white. Searches of areas along the margins of the mine (closer to the ground surface and country-rock) yielded colorful steatite samples that were much more Harappan-like in appearance.

<u>Southern Rajasthan</u>

In southern Rajasthan (Figure 7.12 D), settlements belonging to the Chalcolithic Ahar-Banas culture complex (Shinde et al. 2005) like Gilund, Balathal and Ahar are found on the eastern flank of the Aravalli Range and Marwar Plateau area. Although no less than 250 km separated these non-urban agro-pastoralists from the Harappans of Gujarat, the rich rock and mineral resources of the region may have brought the two societies into contact.

The lithostratigraphy of southern Rajasthan consists mostly of Precambrian rocks that have been repeatedly “folded, faulted, metamorphosed and migmatized” over the course of last 700 million to two-and-a-half billion years (Prasad et al. 1997: 16). Throughout the complex geologic mélange of the region there are hundreds steatite deposits. They occur in zones or “belts” within ultrabasic (ultramafic) igneous rocks (in this case of the non-ophiolitic variety) and in sedimentary magnesium carbonate rocks (Gahlot and Shukla 2000: 111-112). Because these belts often cross district boundaries, I discuss the deposits that were sampled in this region according to their parent-rock types rather than their geographic location. Sources of dolomitic origin are marked with green symbols on Figure 7.12 D while black symbols mark those of ultramafic origin.

One note before proceeding. Throughout this entire section I have taken great pain to discuss not only the deposits of Harappan quality stone that I sampled but also all other occurrences (of any nature or quality) that I visited or read about in the geologic literature. This was necessary in order to provide a rough indication of how representative the sources that I sampled were of the deposits present in each region (or at least those documented in each region). In southern Rajasthan the situation is different, however. There were a dozen or so mines and outcrops in the region that I visited but sampled only sparingly (or not at all) because the material at them was subpar. There is no need to mention them below because there are unquestionably hundreds more like them. Nor is it necessary to try to list the plethora of excellent quality steatite deposits that I was unable to visit. It is enough to recognize that the materials collected, although carefully selected to be geographically and geologically representative, constitute an extremely small sample of steatite in this region.

Dolomitic occurrences sampled

The various dolomitic formations of southern Rajasthan all belong to the Early Proterozoic (ca. 2500 – 2000 m.y.a.) *Aravalli Supergroup* of rocks (Gupta et al. 1997).

In the Rajsamand District, a belt of steatite extending around 29 km occurs in the dolomitic marble of the Haldighathi Formation (Gahlot and Shukla 2000: 111-112; Gupta et al. 1997: *geologic map*). Samples were collected at two mines around five kilometers apart in the center of this zone – Karoli (RKA) and Rabcha (RRA). In the central Udaipur District, steatite in Kathalia dolomite was sampled at Dev Pura (RDV) mine. This deposit lies just 12 km southeast of the famous lead-zinc mines at Zawar (Freestone et. al 1985; Craddock et al 1989). In the southeastern part of the Udaipur district, a belt of steatite in Jagpura dolomitic begins near Salumbar mine (RSA) and terminates 40 km to the southeast at the massive Deola (RDP) open-pit mine in the Dungarpur District (Department of Mines and Geology 1992: 13; Gupta et al. 1997: *geologic map*). Samples for this study were collected from each of those locations.

Ultramafic occurrences sampled

Steatite deposits of ultramafic origin in southern Rajasthan are hosted within rocks of the Rakhabdev Ultramafic Suite, which occurs in three belts (Gupta et al. 1997: 158-159). Geologic samples for this study were taken in the southernmost and largest belt (it actually diverges into two sub-belts) that extends from the Udaipur District into the Dungarpur District. From north to south the six mines and/or outcrops sampled were: Kali Ghadi mine (RKG), Shiv Bola mine (RSB) and the nearby (1.5 km) outcrop at Rishab-der (RRD), Khadi Ghati mine (RSH), Shala Shah Thana mine (RST) and Manpur mine (RMP).

Steatite occurrences in Gujarat

The southern fringes of the Aravalli Range extend across the Rajasthan border into the northeastern part of Gujarat. Geologically, the steatite-bearing formations in that trans-border area are continuations of those to the north. The steatite deposits found in them would have been the absolute nearest sources of that stone for the Harappans of Gujarat – a fact already noted by S.R. Rao (1985: 583) in his discussion of steatite artifacts at Lothal.

Steatite samples were collected around the Dev Mori (Devni Mori) area (at Bhiloda and nearby Kundol – DMB & DMK) in the Sarbarkantha District (Indian Bureau of Mines 1992: 108; Middlemiss 1912). These deposits and six additional ones found within 10 to 35 km of Dev Mori (see Chatteerjee 1964: 436 for deposit names) are part an outlying sub-belt of the Rakhabdev Ultramafic Suite, which was discussed in the preceding section.

Around 125 km farther south, another cluster of steatite deposits is found in the Vadodara and Panchmahal districts (Geological Survey of India 2001a: 76). All occur in the dolomitic limestone formation of the Precambrian Champaner Group (Dwivedi 1984). Samples representing this cluster were taken at Gandhra (GPM) in the Panchmahal District.

A brief note on steatite occurrences in other regions

Two other regions should be noted in closing. The steatite deposits of Afghanistan, especially those in its eastern provinces (identified in ESCAP 1995; Orris and Bliss 2002; Peters et al. 2007), must be considered potential sources. Also, the clear evidence of Harappan interaction with the Oman region (Cleuziou 1992) opens the possibility that steatite from the extensive Semail ophiolite of the eastern Arabian Peninsula may have made its way, perhaps with copper from that formation, to consumers in the Indus Valley.

A geologic provenience study of steatite artifacts from Harappa and seven other sites

A set of unfired steatite artifacts from Harappa and seven other archaeological sites was presented in the first section of this chapter. The various steatite occurrences of the Greater Indus region from which those artifacts potentially may have been acquired were discussed in the second. In this section, I provide the details and results of a geologic provenience study in which INAA-derived data was used to compare the archaeological set to geologic samples collected from over three dozen of those potential sources. Before doing so, however, I review various geologic provenience studies of steatite artifacts that have been conducted in the past. In terms of the present undertaking, those studies provided both models to follow and examples of what to avoid.

Past geologic provenience studies of steatite artifacts

The use of quantitative methods in attempts to differentiate steatite deposits and/or assign geologic proveniences to steatite artifacts go back more than 60 years to Bullen and Howell's spectrographic analysis (1943) soapstone sources in New England. Although that initial study provided inconclusive results, more research later followed with varying degrees of success. Kohl and others (1979) used X-ray diffraction (XRD) analysis to examine 375 "softstone" vessels (most were actually chlorite but some were steatite) from sites across southwest Asia and Arabia. Although their results suggested that multiple sources were probably represented among the artifacts studied, the effectiveness of using ratios generated from X-ray peak intensities for provenience resolution proved to be limited (ibid.: 147). Turnbaugh and others (1984) employed macroscopic observations, petrography and major element profiling using atomic absorption spectrometry in a study

of six southern New England soapstone quarries. Although they documented significant inter-quarry compositional variation, it was unclear if this combination of techniques could be used to confidently assign provenience to artifactual materials (ibid.: 137). Recently, Magee and others (2005) conducted a promising pilot study of 15 "softstone" (both chlorite and steatite) vessel fragments from two Iron-Age sites in southeastern Arabia using ICP-MS/OES (optical emissions spectrometry). Focusing on measured concentrations of transition metals, their results indicated that stone from multiple distinct sources was likely represented among the artifacts. This method could eventually be an effective tool for provenience determination when samples from geologic sources are included in a dataset.

The most successful geologic provenience studies of steatite artifacts to date have involved instrumental neutron activation analysis (INAA). The use of this method was pioneered by Ralph O. Allen and others at the University of Virginia who, after concluding that the relative concentrations of rare earth elements (REEs) remained more or less constant throughout steatite occurrences, characterized numerous quarries and soapstone artifacts in the eastern United States and Canada (Allen et al. 1975; Allen and Pennell 1978; Luckenbach et al 1975; Rogers et al. 1983). Measured REE concentrations from quarries were normalized by dividing them by REE in concentrations chondritic meteorites. An REE distributional curve profile or "fingerprint" for each quarry was generated against which chondrite-normalized REE profiles of steatite artifacts could be compared and matched. Although this seemed to work very well for Allen and his associates, Moffat and Buttler (1986) called the whole approach into question after finding that REE concentrations were too low and too variable in Shetland Islands steatite sources to be of

use in provenience studies of artifacts from that region. To be fair, the extended count times employed by Allen and others (Pennell 1978 cited by Truncer 1998: 24) generated data that was much more precise than that produced by Moffat and Buttler's comparatively short measurements. However, some valid points were made regarding the need for more rigorous sampling to assess intra-source variability as well as about the usefulness of REE-profiles as quarry "fingerprints." Truncer and others (1998) took up these issues in a study at the University of Missouri Research Reactor (MURR) that partially involved the re-sampling and analysis of a number steatite quarries in eastern North America previously characterized by Allen's group. They found INAA to still be an effective technique for differentiating individual sources and assigning geologic provenience, at least on a regional level, to soapstone artifacts. Importantly, they discovered that transition metals, rather than REEs, contributed most to steatite source discrimination and that canonical discriminant analysis (CDA) was a more appropriate method of data evaluation than REE "fingerprints."

The present study is largely modeled after Truncer and other's successful 1998 research project. It employs INAA (although irradiation and count times at the UWNR differ from those used at the MURR), focuses heavily on transition metals and relies mainly on CDA for source discrimination and provenience assignment. It differs somewhat from that and most of the other studies discussed above in its definition of what constitutes a steatite "source" and the expectations of provenience resolution stemming from it. Here a "source" area is considered to be a distinct *geologic formation* in which bodies of steatite occur, rather than an individual outcrop or quarry. For Harappa, which lays no less than 325 km from any steatite source, this level of geographic resolution is more than sufficient.

Details and results of the present study

One hundred forty unfired steatite artifacts from Harappa, thirty-seven such artifacts from the seven additional sites and 442 geologic samples collected from 37 deposits of Harappan-quality steatite around the Greater Indus region were analyzed using INAA. Sample preparation and irradiation followed those procedures outlined in Chapter 2. For the geologic samples, the measured concentrations for 11 elements (Al, Co, Cr, Eu, Fe, La, Mn, Na, Sc, V and Zn) can be found in Appendix 7.3. For the archaeological samples from Harappa those data are listed in Appendix 7.4; for Mohenjo-daro in Appendix 7.5; for Mehrgarh and Nausharo they are in Appendix 7.6; and for all remaining archaeological samples (from Gola Dhoro, Nagwada, Loralai and Tepe Hissar) they are in Appendix 7.7. INAA-derived data were evaluated using CDA and cluster analysis (CA), again following procedures discussed in Chapter 2. Appendix 7.8 lists the standardized (canonical) discriminant function coefficients for all scatterplots (below) generated using CDA.

Initial CDA and CA comparisons of all steatite artifacts to the geologic sources

Examination of the INAA results begins with a comparison of the geologic sources only. On Figure 7.13, the 442 geologic samples are plotted using the first and second discriminant functions generated from CDA of the 37 deposits. The symbols representing steatite samples from dolomitic parent-rock are those in shades of green (some have black or white elements) while the ones representing samples from ultramafic sources are in black and/or black and white. The map of the Greater Indus region (Figure 7.2) at the beginning of this chapter and the detail maps from the preceding section (figures 7.9 A, 7.10 A and 7.12 A through D) serve as the symbol key for the geologic samples.

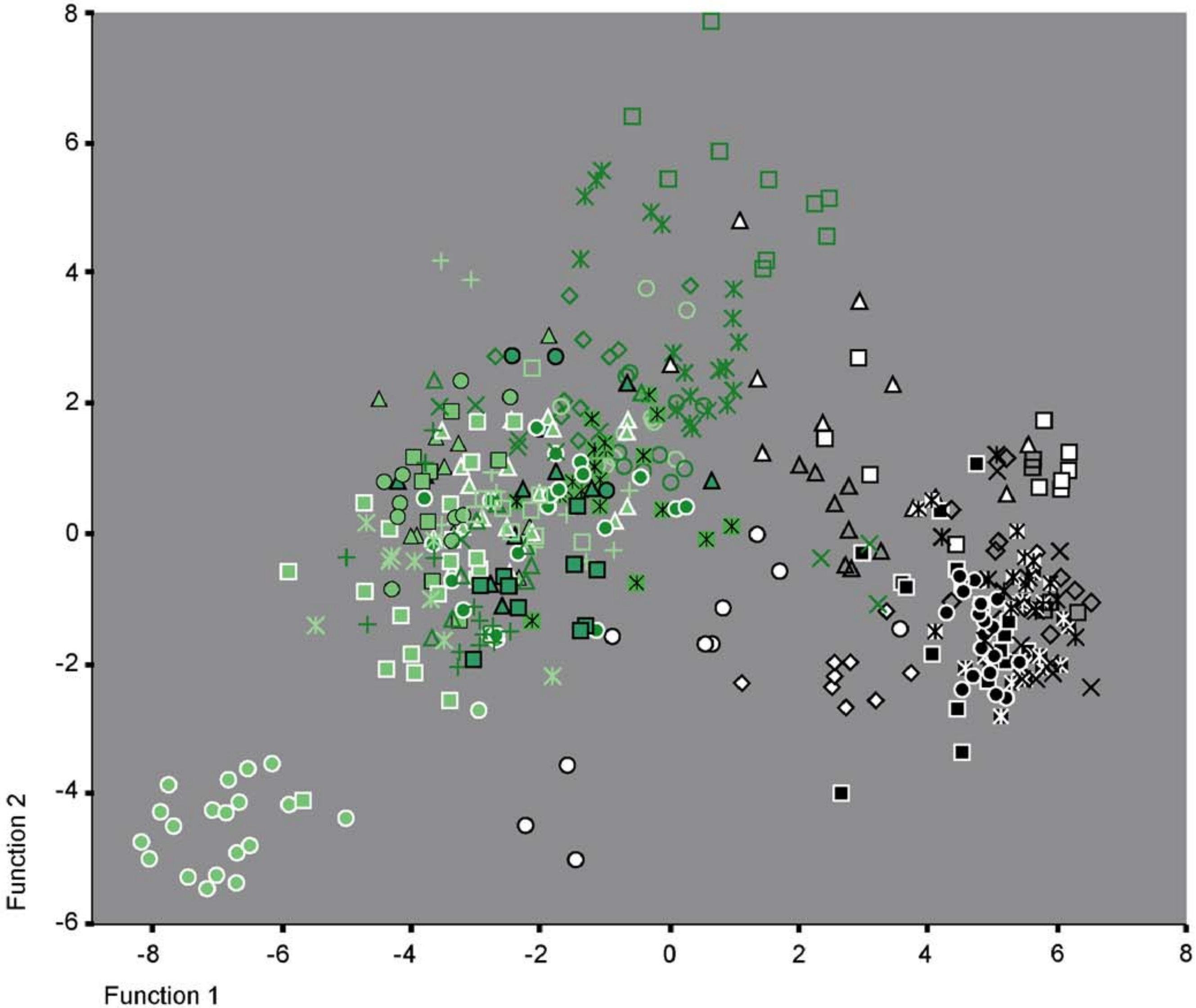


Figure 7.13

All 442 geologic steatite samples from the 37 locations are compared. Each location is evaluated as an individual group

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, Sc, V, Zn

Symbols representing samples from **dolomitic** parent-rock are those in shades of green (some of them have black or white elements). Symbols that represent steatite from **ultramafic** sources are in black and/or white only.

For **key** to source symbols see figures 7.2, 7.9 A, 7.10 A and 7.12 A to D

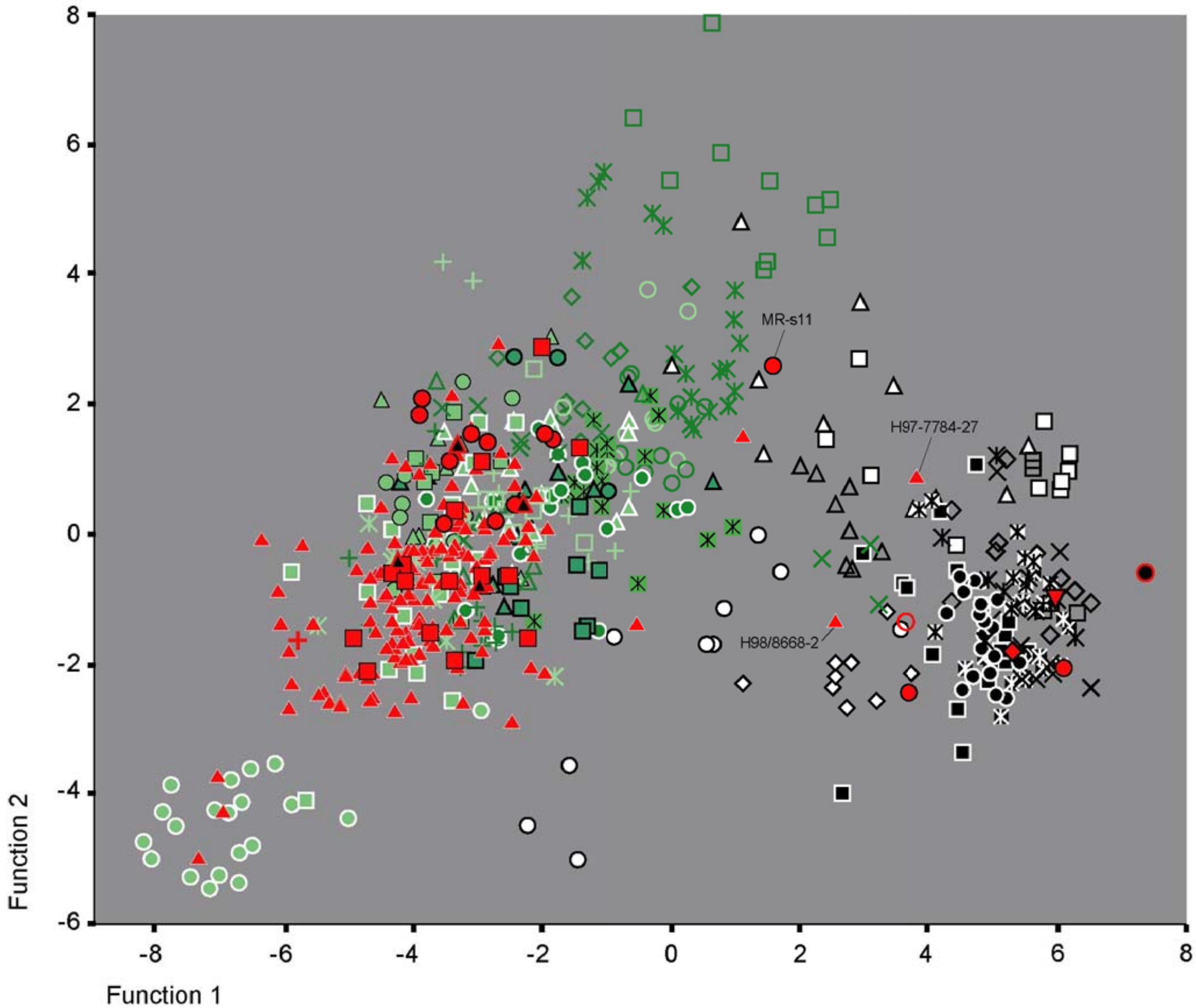


Figure 7.14

All 177 steatite **artifacts** analyzed for this study are plotted as ungrouped cases in relation to the 442 geologic samples.

Discriminant functions generated using the elements Al, Co, Cr, Eu, Fe, La, Mn, Na, V, Zn

Artifact key

- ▲ Harappa
- ■ Mohenjo-daro
- ● Mehrgarh
- ● Nausharo
- + Loralai fragment
- ○ Loralai beads
- ▼ Gola Dhoro
- ◆ Nagwada
- ▲ Tepe Hissar

It is clear from the two distinct clusters of datapoints on Figure 7.13 that steatite deposits of dolomitic and ultramafic origin are geochemically distinct from one another. This is because the ultramafic steatite samples have a higher average concentration of certain transition metals (in particular Co, Cr, Fe, Mn and Sc) as compared to the dolomitic samples, which have higher concentrations of the two REEs Eu and La (Figure 7.15).

Figure 7.15: Average elemental concentrations (PPM) in dolomitic vs. ultramafic steatite sources

element	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
dolomitic *average*	15170	9.2	24	0.26	14854	3.69	80	1065	2.45	23.7	78.5
ultramafic *average*	13156	69.1	1297	0.16	30458	1.53	286	538	4.14	24.4	56.5

A minor amount of overlap between the two large clusters of deposits representing the two different parent-rock types is, however, evident on the plot. Most of it comes from two deposits – Urgasai Nasir (ZUN) and Takhahen (ZTAK), both of which are in the Muslimbagh ophiolite of northern Balochistan. At certain places, the ultramafic rock of that formation comes into contact with Mesozoic limestones and shales (Ahmad 1974: 4; Ahmad and Abbas 1979: 245). Although more detailed field studies are needed to confirm this, ZUN and ZTAK are *perhaps* deposits formed where hydrothermal alteration has occurred at the point of contact between the two types of parent-rock. The result might then be steatite bodies having concentrations of certain metallic elements that are higher than usual for dolomitic occurrences but somewhat lower than is typical of ultramafic ones.

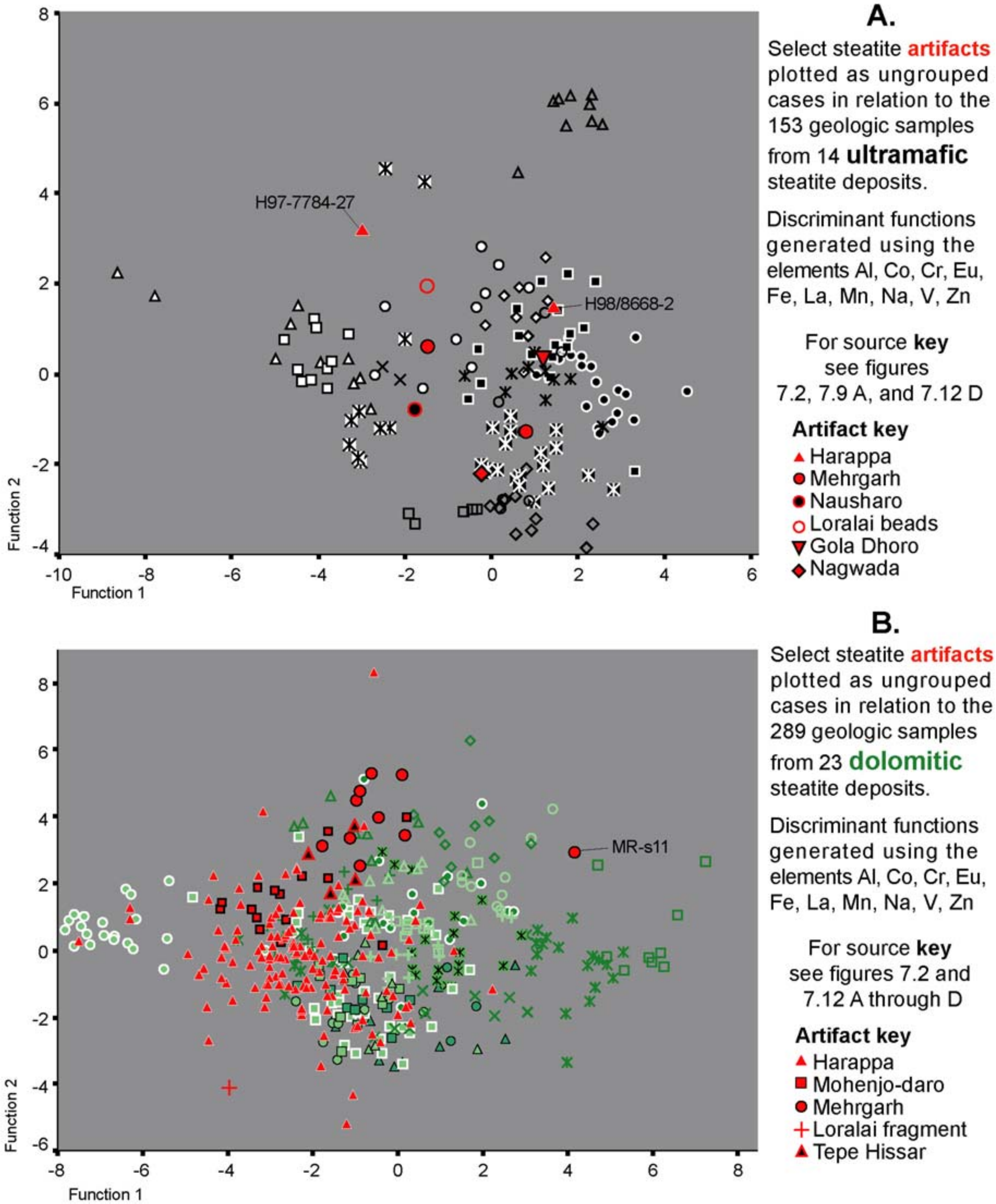
A second area of overlap is associated with the Rabcha deposit (RRA) of southern Rajasthan. Three samples from that source had uncommonly high Co and Cr concentrations for a dolomitic deposit.

In spite of areas of overlap, good separation overall between the groups of samples comprising the full geologic set was achieved. When the leave-one-out cross-validation function was applied, exactly 69% of grouped geologic cases were classified correctly.

When the set of 177 artifacts are plotted as ungrouped cases in relation to the geologic samples (Figure 7.14), one thing becomes immediately clear. That is, the vast majority of the unfired steatite artifacts analyzed are composed of raw material derived from deposits of dolomitic origin. Only a handful (8 of 177) of the artifacts in the archaeological set plot in or near the cluster created by samples from ultramafic deposits. The first predicted group memberships (PGMs) for artifacts from Harappa made in this initial CDA can be found in Appendix 7.1 in the column labeled "full set" (meaning they were made in a comparison to the full geologic set). The two to five letter source codes listed correspond to those given in the text as well as those listed in column four of Appendix 7.2.

For the second round of CDA (Figure 7.16) the geologic samples were divided into two sub-sets according to their parent-rock type (ultramafic or dolomitic) and then those artifacts that had been predicted to belong to deposits of each type in the first round of analysis were compared to them as ungrouped cases. Slightly better separation than before was achieved for both sub-sets. For deposits of ultramafic origin, 71.2% of cross-validated grouped geologic cases were classified correctly while 71.3% for dolomitic sources were classified correctly. The first and second PGMs for artifacts from Harappa made in these second-round analyses are listed in Appendix 7.1 under the column heading "parent-rock." Those results are examined in detail in the section that follows this one. The PGMs for steatite artifacts from the seven other prehistoric sites are discussed in the section after that.

Figure 7.16: CDA comparison of select steatite artifacts and sub-sets of geologic samples representing different parent-rock types.



Cluster analyses (CA) were also performed on the full set of 619 steatite artifacts and geologic samples. Multiple clustering strategies were employed and the dendrograms produced in each one (not shown) were, on the whole, very similar to one another. Figure 7.17 is a dendrogram (divided into three parts to fit on a single page) made using the *complete linkage* (also called *furthest neighbor*) method and a squared Euclidian distance measurement. In Appendix 7.9, it is reproduced on 15 pages (sections A through O) and the artifact/sample number for each case in it is provided. Preceding the number for most of the artifacts from Harappa is one of four short codes in parentheses – "(C1)" through "(C4)." These codes, which denote a numbered cluster in which the artifact is a member, are used in a later CA of just the 140 archaeological samples from Harappa (Figure 7.21).

As in the original CDA of the full geologic set (Figure 7.13), samples from ultramafic sources form a group/cluster that, for the most part, is highly distinct from those formed by samples collected from dolomitic deposits. Four "main" clusters – one entirely composed of ultramafic samples and three entirely or mainly composed of dolomitic ones, were designated (discussed below) and are labeled on Figure 7.17. There is a modicum of overlap between the two types of geologic parent-rock and, as before, it is due mostly to samples from two deposits (ZTAK and ZUN) in the Muslimbagh ophiolite clustering among the dolomitic sources. A small number (10) of samples from other ultramafic deposits (LBW1 and RST) also appear in the dolomitic clusters. None from dolomitic sources appear within the ultramafic cluster, however. As in the original CDA comparison of the full archaeological set to the full geologic set (Figure 7.14), the great majority of steatite artifacts (170 of 177) cluster with samples from the various dolomitic sources.

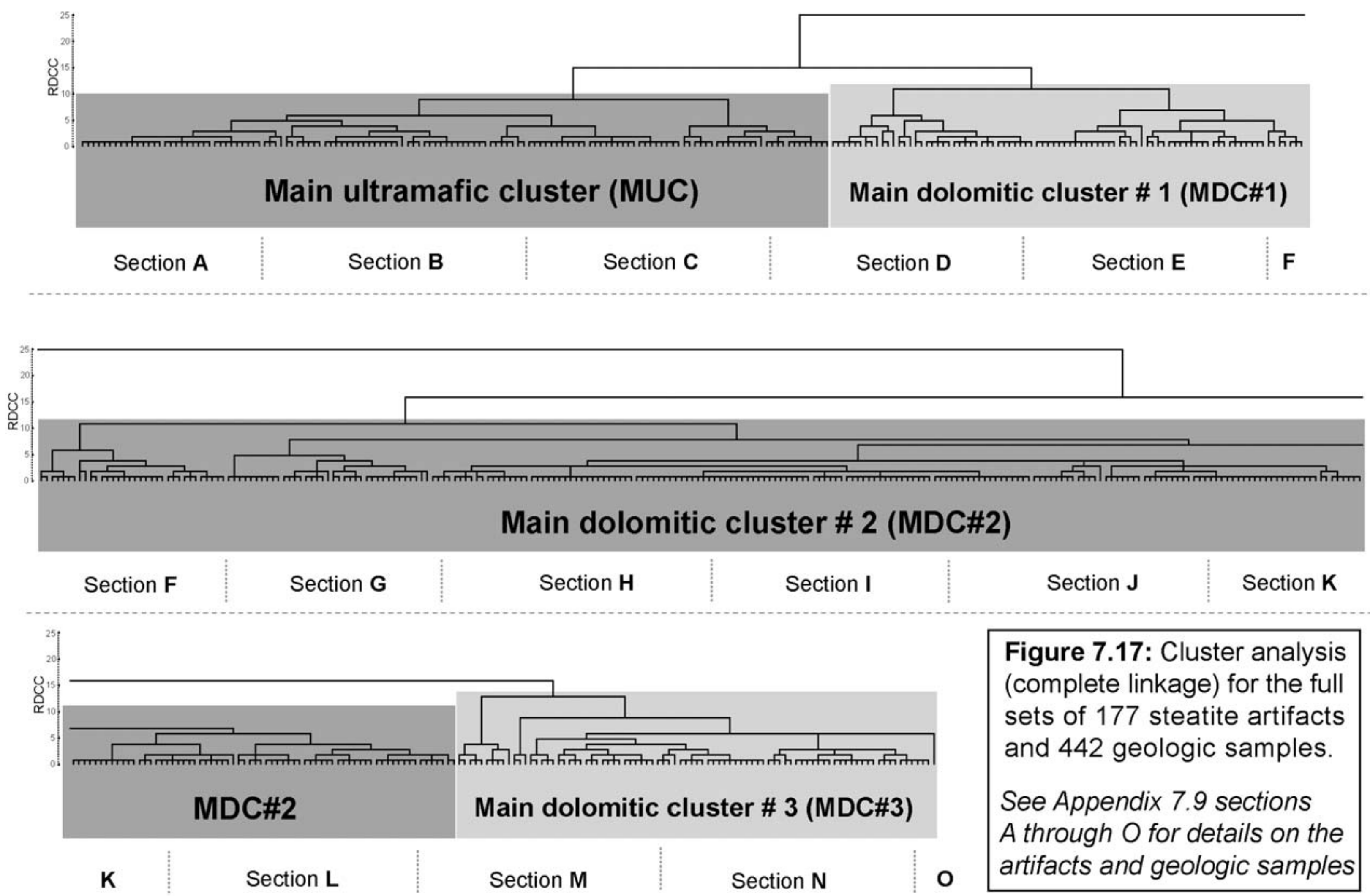


Figure 7.17: Cluster analysis (complete linkage) for the full sets of 177 steatite artifacts and 442 geologic samples.

See Appendix 7.9 sections A through O for details on the artifacts and geologic samples

On each dendrogram there is a numbered axis that is labeled *rescaled distance cluster combine* (or RDCC). This scale is used to indicate the similarity/dissimilarity between two clusters by providing the value for the point that they meet (join or split). RDCC values are generated by rescaling the various distance measurements made in the CA from 1 (closest or most similar) to 25 (farthest or least similar). In the initial CA of the full geologic and archaeological sets (Figure 7.17), the two most dissimilar clusters (those that split at RDCC 25) were: 1) a combined group (macrocluster) consisting of both a cluster of ultramafic samples and artifacts and a cluster of dolomitic ones and 2) another macrocluster made up mainly of dolomitic samples and artifacts. The former macrocluster splits at RDCC 15 (noted in section D of Appendix 7.9) and was subsequently divided at that point into the "Main ultramafic cluster" (MUC) and "Main dolomitic cluster #1" (MDC#1). The latter macrocluster was divided into main dolomitic clusters #2 and #3 (MDC#2 and MDC#3) based on a split that occurs at RDCC 16 (Appendix 7.9 Section J).

There are numerous other distinct clusters evident within each of the four "main" ones that have defined (Figure 7.17). However, no designations are given to them at this point because none represent complete, geologically homogenous groups. That is to say, none of the individual geologic sources in the dataset can have all of its members encompassed into a single cluster without also having members from other geologic sources included in it. The reason for this is that many deposits in the geologic dataset are highly variable geochemically as well as compositionally similar to one another. Consequently, samples from many deposits spread widely across the dendrogram, clustering near those from different sources that are compositionally like them. Whereas

there was a very minor degree of overlap between the ultramafic and dolomitic sources when they were considered as unified groups, at a level of comparison involving individual deposits the degree of overlap is much more significant. The outcome has already been seen in the results of the initial CDA of the datasets discussed above. Because of the overlap between various deposits in the geologic dataset, group discrimination is imperfect. This continues to be the case in CDAs performed in the next section. The correct classification success rate for cross-validated geologic samples will, at best, only ever approach around 80%. What it means for this study is that it is not possible to simply observe where an artifact falls on the CA dendrogram, note which geologic samples cluster with it and make a specific provenience determination based on that observation.

In spite of the overlap issue, a great deal of information, including much regarding the possible geologic proveniences of unfired steatite artifacts, can be gleaned from the dendrogram of the full archaeological and geologic sets (Figure 7.17). However, because the data depicted are very complex, effectively interpreting it requires having a full and detailed understanding of the variability of the geologic samples and of the associations that the artifacts have with them. This is gained through multiple CDAs of refined and regrouped versions of the geologic dataset along with CAs that focus on specific sub-sets of artifacts. These analyses are detailed in the next section, as artifacts from Harappa are first put through a series of CDA comparisons to the geologic set and then evaluated (both as a separate assemblage and in relation to the full geologic set) using CA. The results are then interpreted with reference to the three lines of inquiry outlined in Chapter 1. In the subsequent section, the artifacts from the other sites are similarly analyzed and interpreted.

Unfired steatite artifacts from Harappa

Canonical discriminant analyses

When compared by CDA to samples from the 37 geologic deposits (Figure 7.14), the predicted group membership (PGM) for 138 of the 140 steatite artifacts from Harappa was one of the dolomitic sources. The two artifacts predicted to belong to an ultramafic deposit are labeled on figures 7.14 and 7.16 A. H98/8668-2 – the BMAC wig (Figure 7.5 E), was assigned to the Sakhakot-Qila deposit (KOT) of the NWFP. H97-7784-27 – a sawn fragment, was assigned to the Duddo deposit (LBW1) of southern Balochistan. These PGMs are evaluated and their implications discussed at the end of this section.

We now focus just on the 138 unfired steatite artifacts from Harappa that in the first CDA of the full geologic set (Figure 7.14) were predicted to belong to one of the dolomitic sources. Figure 7.18 is a summary table of the PGMs from that analysis and from three subsequent ones (PGMs are listed for each individual artifact in the final four columns of Appendix 7.1). Out of the 23 dolomitic deposits sampled (each of which was treated as an individual group during CDA) only 14 had any of the 138 artifacts assigned to them during the various CDAs. In the first two columns of Figure 7.18, those 14 are listed according to the region in which they are found. The third column shows the number of unfired steatite artifacts that were predicted in the initial "full set" CDA to belong to each of those deposits. The first highest PGM for 87 of the artifacts (63% of the total number) was one of the three Sherwan zone deposits in the Hazara District of the NWFP. Seventeen were assigned to the Painthal, Jammu source; thirteen to the Prang Dera deposit in the Khyber Agency and five to the Daradar deposit in the Safed Koh Range of the Kurram Agency.

Figure 7.18: Predicted group membership (PGM) summary table for four CDAs of the138 unfired steatite artifacts from Harappa belonging to dolomitic sources

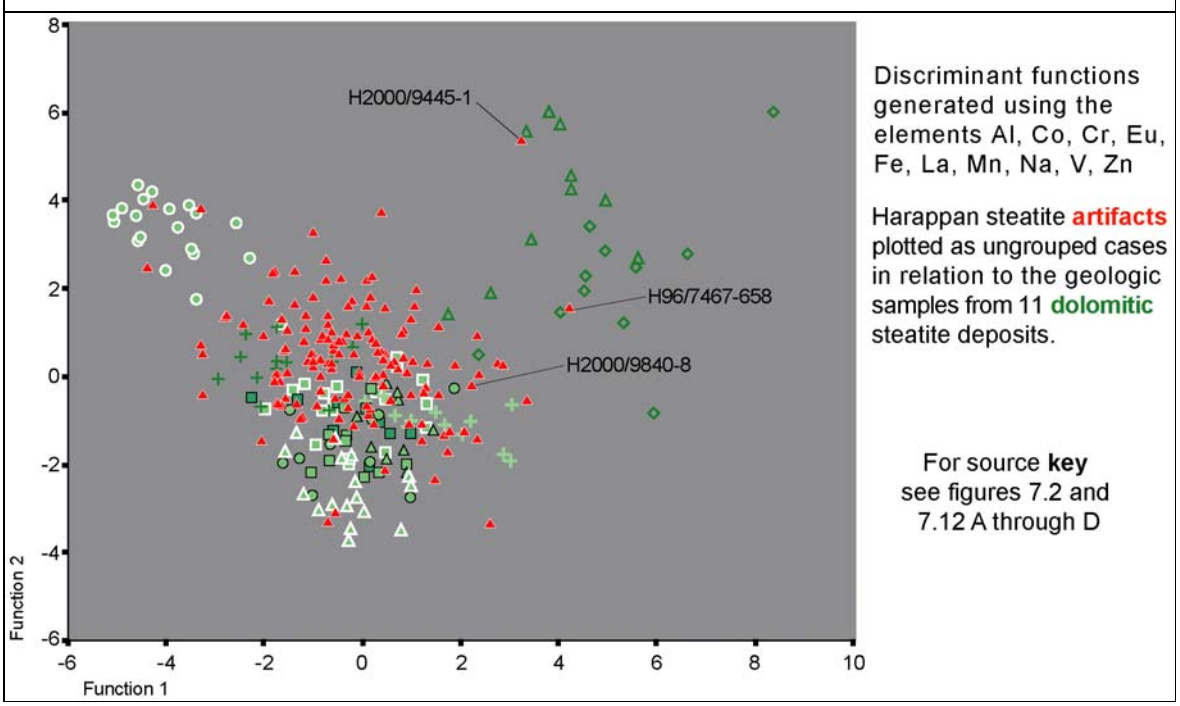
region	*deposit*	Full geologic set 1st PGM	All dolomitic sources 1st PGM	2nd PGM summary for All dolomitic sources analysis	11 dolomitic sources 1st PGM	Regional dolomitic 1st PGM
FATA	Kurram-Daradar (PD)	5	6	SB*x*4, SKK *x*2	6	PD 14
	Khyber-Prang Dera (LKPD)	13	12	ATM, BESH *x*3, RDP *x*2, SB, SC *x*4, SKK	14	LKPD 15
NWFP	*Sherwan deposits* Bandi (SB)	57	47	ATM, JKK *x*2, PD *x*7, RSA *x*2, LKPD *x*7, SC *x*2, SKK *x*26	40	Sherwan (SB,SC, SKK) 83
	Chelethar (SC)	13	14	JJG, LKPD, RDP, SB *x*3,SKK *x*8	16	
	Khanda Khu (SKK)	17	18	PD, SB *x*10, SC *x*6, UB	38	
Jammu	Painthal (JAMPT)	17	19	BESH, LKPD, RSA *x*7, SB *x*5, SKK *x*2, USK *x*3	14	JAMPT 16
Uttaranchal	*Bageshwar deposits* Chatikhet to Kanda (UB)	0	1	SC	0	Uttaranchal (UB,US, USK) 2
	Shishi Khani (USK)	2	2	SKK *x*2	2	
Northern Rajasthan	*Alwar deposits* Nangalhari-Bairaswas (ANB)	1	1	ATM	2	Alwar &Dausa (ANB, ATM ASM, DGT) 0
	Teori (ATM)	4	4	JJK, RSA, SB *x*2	2	
	Jhunjhunu-Kho (JKK)	3	5	ATM *x*2, RDP, SB *x*2	0	Jhunjhunu (JJC, JJG, JJK) 5
Southern Rajasthan	Dungarpur-Deola (RDP)	1	1	SC	2	Southern Rajasthan (RRA, RKA, RDV, RSA, RDP) 3
	Udaipur-Salumbar (RSA)	5	7	LKPD, SB *x*3, SKK *x*2, USK	2	
	Rajsamand-Karoli (RKA)	0	1	PD	0	

In total, 122 of the 138 artifacts most closely resembled steatite from deposits in a region 330 to 445 km north of Harappa. I will frequently refer to this as the "northern" region. Of the remaining 16 artifacts, the first PGMs for eight were in northern Rajasthan, six were in southern Rajasthan and the PGM of two was the Shisha Khani deposit in Uttaranchal. This initial CDA has not only shown that residents of Harappa were almost exclusively using dolomitic steatite, but also indicated that the majority of it was likely acquired from deposits in the "northern" region, in particular those in the Sherwan zone. Only a small percentage (≈ 12%) of this variety of stone appeared to be from deposits in other regions.

Next, we examine the results of the second CDA (Figure 7.16 B) in which artifacts of dolomitic origin were compared only to samples from the 23 dolomitic deposits in the geologic set. The fourth column of Figure 7.18 (heading "all dolomitic sources") shows the number of the 138 examples from Harappa predicted to belong to each of the 14 deposits that were assigned artifacts. The first PGMs for this analysis were largely the same as in the initial one. Only 19 artifacts (or around 14%) were reclassified. For several of those cases, the new prediction was another deposit in the same geologic formation (such as SKK being reclassified as SC in the Sherwan zone) and for many others it was another deposit in the same general region (such as SB in the Sherwan zone changing to JAMPT in Jammu). The first highest PGM for 79 of the artifacts (57% of the total number) was one of the three Sherwan deposits and, altogether, 116 artifacts were assigned to sources occurring in the general region to the north of Harappa. The remaining 22 were predicted to belong to deposits in Uttaranchal and Rajasthan. Two additional deposits – Karoli in southern Rajasthan (RKA) and Chatikhet/Kanda in Uttaranchal (UB), were assigned an artifact each.

Several additional rounds of CDA were performed in which those deposits *not* predicted to be a source of any of the artifacts were removed from the geologic set. The refined set was then re-analyzed and re-compared to the dolomitic artifacts from Harappa. Throughout this process the artifact PGM patterns remained more or less the same. Finally there came a point when 11 deposits remained in the dolomitic sub-set, each of which was predicted to be the source of at least one artifact. Figure 7.19 is the scatterplot from that last CDA. Nearly 80% (78.8%) of cross-validated grouped cases now classified correctly. The PGM summary is in Figure 7.18 under the column heading “11 dolomitic sources.” This time around 94 of the 138 artifacts (68%) were assigned to one of the Sherwan deposits. Together with those from Jammu and the FATA, a total of 128 artifacts (93%) were predicted to belong to “northern” region sources. Only ten artifacts were assigned to groups made up of samples from deposits in Rajasthan or Uttaranchal.

Figure 7.19: CDA comparison 138 steatite artifacts from Harappa and select dolomitic sources

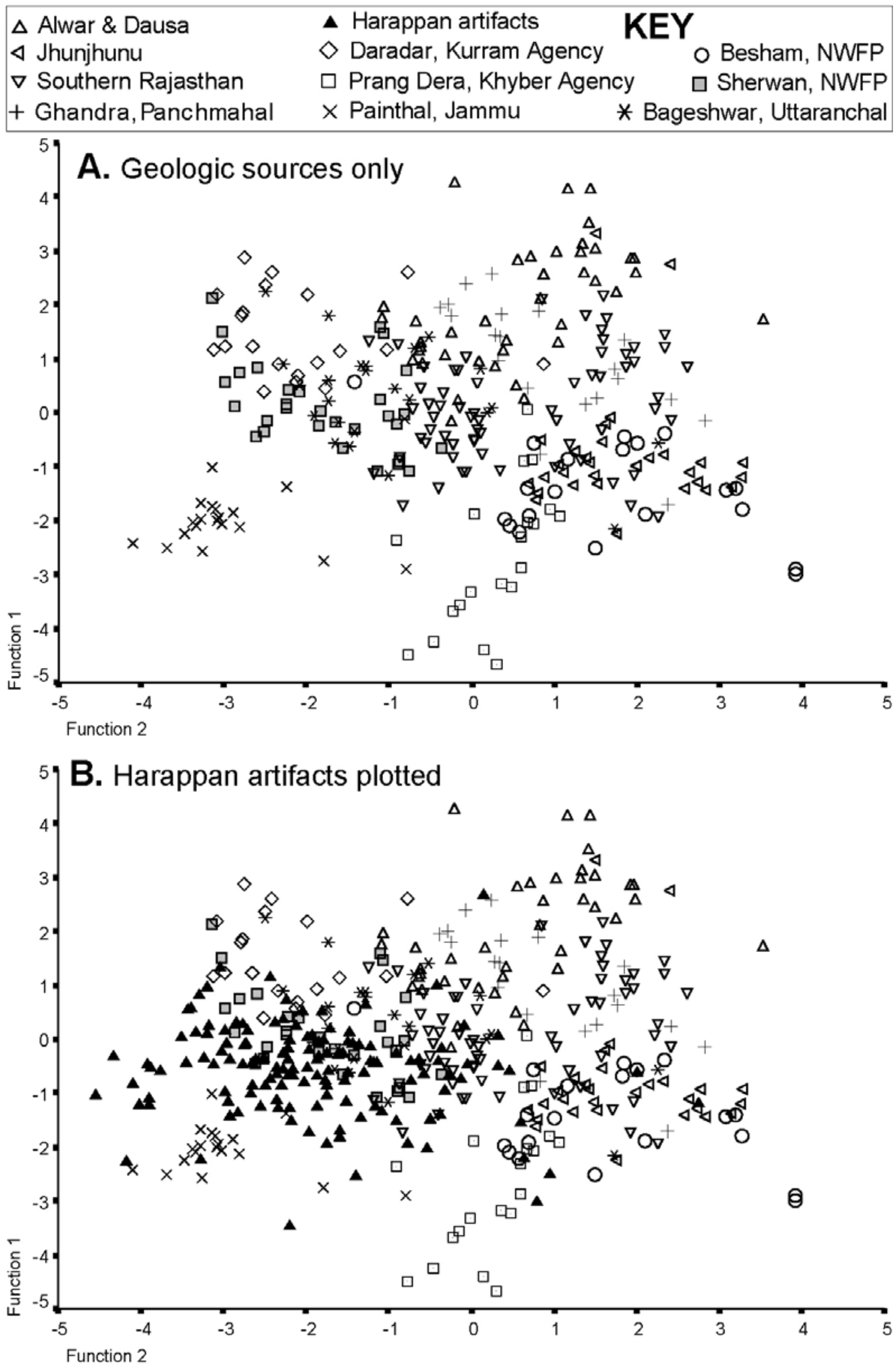


One final CDA involving the 138 dolomitic artifacts from Harappa was performed. For this one, all dolomitic deposits occurring within the same geologic formations were combined to create new *regional* groups. So, for instance, the three deposits sampled in the Abbottabad Formation of the Hazara District, which had previously been treated as separate groups, were combined into one new group designated "Sherwan." In this way, new regional groups were created (and named) for "Uttaranchal," "Jhunjhunu," "Alwar & Dausa" and "southern Rajasthan." Those deposits that were the only occurrence sampled in a particular formation were left unchanged and retaining their original source codes.

It was expected that some discriminatory power would be lost by combining broadly related deposits in this way. Indeed, when the leave-one-out cross-validation function was applied to the regrouped dataset the correct classification success rate fell to 66.8% – slightly lower than what it had been for the original CDA of the full geologic set. However, combining deposits allowed significantly larger groups to be compared, thus providing more statistically secure appraisals. Whereas in the sub-set of 23 dolomitic deposits no group had more than 20 members, the ten groups now in the set ranged in size from 20 (for the individual deposits) up to 65 members (for the southern Rajasthan group).

Figure 7.20 A shows the re-grouped geologic samples plotted according to their first and second discrimant functions. On Figure 7.19 B, the 138 Harappan artifacts are plotted as ungrouped cases in relation to the samples. The PGMs for this analysis are found in Appendix 7.1 and are summarized in Figure 7.18 under the column headings "regional dolomitic." Eighty-three artifacts were predicted to belong to the Sherwan group while 14, 15 and 16 artifacts were, respectively, assigned to the Daradar (Kurram), Prang

Figure 7.20: CDA comparison of regional dolomitic steatite source areas and Harappan artifacts



Dera (Khyber) and Painthal (Jammu) deposits. Only ten artifacts were assigned to groups made up of samples from deposits in Rajasthan or Uttaranchal.

Repeated comparisons of the unfired steatite artifacts from Harappa to refined and/or regrouped versions of the geologic dataset produced PGMs that were largely consistent with one another from analysis to analysis. However, before simply using those as provenience determinations it is important to be mindful of a few things. First, in CDA each ungrouped case (artifact) is assigned a PGM regardless of its similarity or dissimilarity to any of the groups (deposits) within in a dataset. So in this study the possibility exists that one, several or even all of the artifacts do not actually belong to any of the deposits in the geologic dataset despite being assigned to one. Secondly, recall from the discussion of CDA in Chapter 2 that group membership is predicted based on an individual case's Mahalanobis distances to the various centroids of groups in a dataset. There is a chance that an artifact that genuinely belongs to deposit *A* will be predicted to belong to deposit *B* because it happens to lie closer (has a lower Mahalanobis value) to deposit *B*'s group centroid. The reason may be that the artifact is a distant compositional outlier of deposit *A* or because geochemical similarities between the deposits *A* and *B* have resulted in a degree of overlap among the individual cases making them up. Regarding the latter possibility, I would point out that the classification success rate for cross-validated grouped cases in the geologic set was, at best, around 80%. This indicates that although source discrimination was good, it was far from perfect. It is for precisely this reason that I have provided the *second* highest group membership predictions (as determined by which group centroid has the second lowest Mahalanobis distance value) after the first PGMs with

the results of the "parent-rock" analysis (in Appendix 7.1 this is written as "1st PGM / 2nd PGM"). There is also a summary of these second PGMs in fifth column of Figure 7.18. As artifact provenience determinations are examined more closely below, these second PGMs will be helpful for considering possible alternative source associations.

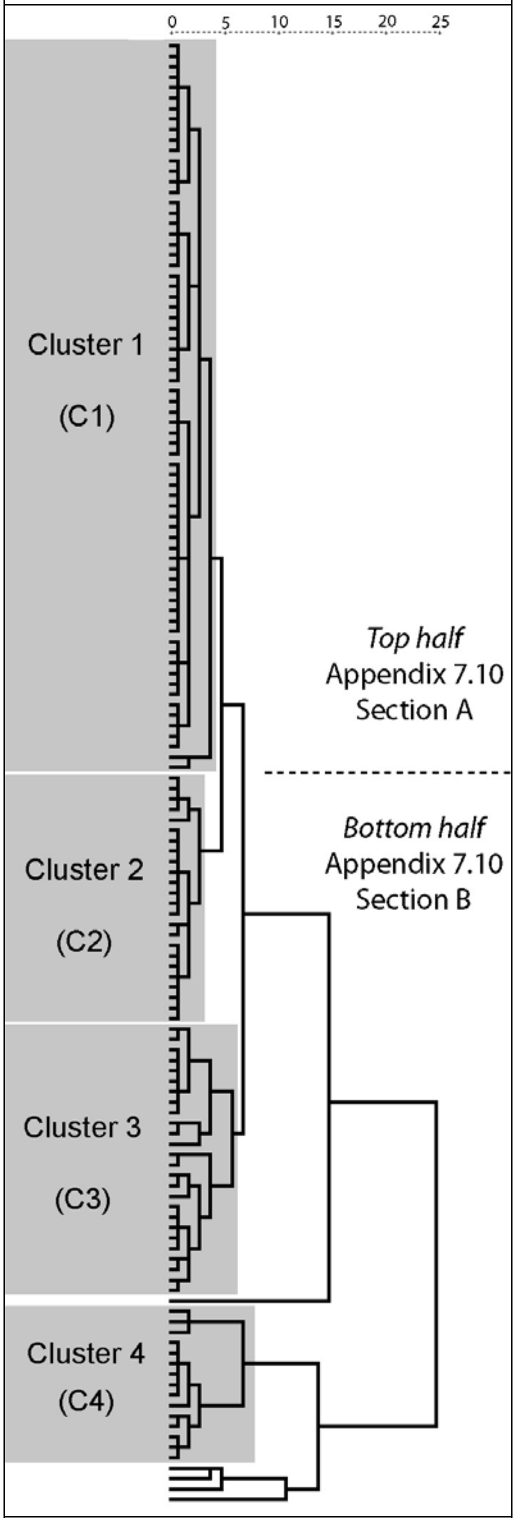
In all the rounds of CDA, the first PGM for the majority of the artifacts from Harappa was one of the Sherwan zone deposits in the Hazara District, NWFP. The majority of that majority also had a second highest PGM in one of the Sherwan deposits. Because of this and because of the large number of assigned artifacts, I feel that this provenience association is a very strong one. Of the remaining artifacts assigned to Sherwan deposits, the second PGM for most was another one of the occurrences to the north of Harappa. Therefore, if any of those happen to actually not come from the Sherwan zone, there is a very good possibility they were derived from the "northern" region.

The provenience associations for artifacts assigned to the Prang Dera (LKPD) and Painthal (JAMPT) deposits appear, for the most part, to be fairly strong. Their numbers did not shift too drastically from analysis to analysis and around half of their second PGMs were deposits elsewhere in the "northern" region. On the other hand, some of them could be outliers of the Sherwan zone, like those assigned to Daradar (PD) perhaps are. In the first three CDAs, five to six artifacts were predicted to belong to the Daradar source and the second PGM for each of those cases was one of the Sherwan occurrences. However, in the final regional-level analysis, nine additional artifacts, many of which had before been assigned to Sherwan, were designated as belonging to Daradar. This could indicate that a number of the artifacts assigned to Sherwan actually derive from other "northern" sources.

Turning now to the artifacts that had first PGMs in other regions, we see that very few (never more than three) were ever predicted to belong to occurrences in Uttaranchal. The second highest PGM for those cases in all analyses was the Sherwan Khanda Khu deposit (SKK). These are very likely compositional outliers from the Sherwan zone. The same is probably also true of many or all of the artifacts predicted to belong to southern Rajasthan deposits (from three to nine in various analyses). On the other hand, the ones assigned to occurrences in northern Rajasthan, although few in number, are somewhat more distinct and *may* be genuinely from that region. They often have second PGMs in the same zone and/or plot apart from the main body of artifacts in the scatterplots. Note, in particular, artifacts H2000/9445-1 and H96/7467-658 (both are identified on Figures 7.19).

Ultimately, it is probably best advised not to treat the PGMs made during the various CDA analyses as hard and fast provenience determinations. Although these predictions may oftentimes provide accurate information about the geologic sources of individual steatite artifacts, they are better (and more reliably) used collectively to reveal broad-scale patterns. When employed in this manner, they help to make a very strong case that most of the steatite acquired by Harappans probably came from sources to the north of their settlement, in particular, those in the Hazara District of the NWFP. Although I advise caution when treating PGMs as firm provenience determinations, I will use those from the refined "11 dolomitic sources" analysis in an upcoming dendrogram (Appendix 7.10) and two tables (figures 7.24 and 7.25) designed to facilitate detailed spatial and temporal examinations of steatite acquisition at Harappa. While doing so, however, close attention is paid to broad-scale patterns and the second PGMs of potentially misclassified artifacts.

Figure 7.21: Cluster Analysis
(Complete linkage / squared Euclidian distance)
of 140 steatite artifacts from Harappa



<u>Cluster analyses</u>

Cluster analyses (CA) were performed on the full set of 140 unfired steatite artifacts from Harappa in order to determine if they grouped ways that might shed additional light on the previous CDA and CA results and, ultimately, provide insights into the use of this rock variety at the site. Analyzing them alone (instead of with other artifacts and geologic samples) allowed better detection of potentially meaningful clusters among the assemblage. Multiple clustering strategies were used, all of which produced very similar dendrograms. The one in Figure 7.21 was made using the same complete linkage method that was used to make the dendrogram of the full archaeological and geologic sets (Figure 7.17). Four clusters (numbered "C1" through "C4") having members that joined between RDCC between 3 (C2) and 7 (C4) were defined. See Appendix 7.10 sections A and B for information (number, contextual data, type and PGM) on the individual artifacts making up the dendrogram.

The first thing to note is that, with the exception of C4, none of the clusters are entirely homogenous in terms of being made up of artifacts assigned by CDA to a single deposit or to a single geologic formation. This was not unexpected since that the cross-validation success rate for the analysis that supplied the PGMs ("11 dolomitic sources") was only around 80%. There was a good chance that some may have been misclassifications. As a result, compositionally related artifacts assigned different PGMs may have clustered together. Another point to note is that although I have defined four main clusters of artifacts, each does not necessarily correspond to single steatite deposit or even an extended zone of steatite formation. There could be artifacts from several unrelated sources represented within a single cluster or, conversely, a single, compositionally diverse source or source area may be represented by multiple clusters. This should be kept in mind as I discuss how the artifacts are distributed in the dendrogram.

Cluster 1 (C1) encompasses the largest group of unfired steatite artifacts. It has 70 members, 56 of which have one of the Sherwan deposits as their first PGM. Of the other 14 artifacts in the cluster, ten are "northern" sources that have second PGMs of Sherwan so it is possible they actually derive from that zone but were misclassified by CDA. Three of the remaining four were predicted to be from the Painthal, Jammu deposit (JAMPT). The final artifact in cluster has a first PGM in the Teori in deposit of northern Rajasthan (ATM) but may be an outlier of the Sherwan zone as indicated by its second PGM (which is SKK).

Eleven of the 15 artifacts predicted to belong to the Painthal deposit make up nearly half of the 24 members of Cluster 2 (C2). Nine of the remaining 13 are assigned to one of the Sherwan deposits. Three of those have a second PGM of Painthal, however. Two

artifacts have a first PGM in the Shisha Khani (USK) deposit of Uttaranchal (with second PGMs in Sherwan) while one is assigned to Deola in southern Rajasthan (RDP).

Eleven of the 14 artifacts assigned by CDA to the Prang Dera deposit in the Khyber Agency (LKPD) are among the 26 members of Cluster 3 (C3). Twelve others artifacts in the cluster were predicted to belong to the Sherwan zone while the remaining three ones have Rajasthan deposits (ANB, RDP and RSA) as first PGMs.

All of the 15 artifacts making up Cluster 4 (C4) have first PGMs in the one of the Sherwan deposits and 13 of 15 of them also have second PGMs in that zone. This is the only homogenous cluster in terms of its members' predicted geologic proveniences.

There are also a few of smaller branches on the dendrogram that are distinct from the four primary clusters. Between C3 and C4 is a single artifact (H2000/9445-1) predicted to belong to Nangalhari-Bairaswas zone (ANB) of northern Rajasthan. Two of the cases in the final small cluster at the bottom of the dendrogram are the artifacts made from ultramafic steatite (discussed at the beginning of this section). Another case (H2000/9840-8) is a fragment assigned to the Sherwan Bandi (SB) deposit. When the ultramafic artifacts are removed and the same CA is performed on the set again (not shown) that particular artifact joins C4. The last artifact (H96/7467-658) on the dendrogram is assigned to the Teori (ATM) deposit of northern Rajasthan. Each artifact (except the ultramafic ones) is noted on the "11 dolomitic sources" CDA scatterplot (Figure 7.19).

The patterns exhibited by the dendrogram shown in Figure 7.21 and by others made using different clustering methods (not shown) helped to support and clarify and much of what CDA previously revealed about the set of dolomitic steatite artifacts from Harappa.

Several artifacts that I had suspected were misclassified as belonging to deposits in Uttaranchal and southern Rajasthan were, in fact, shown to be compositionally similar to the numerous ones assigned to the Sherwan deposits and other sources to the north of the site. Others that were thought to genuinely come from sources outside of the “northern” region were confirmed to be compositionally distinct and likely unrelated to the majority of steatite used at Harappa. Although the PGM makeup of each cluster (except for C4) is mixed (no doubt due, in part, to misclassified outliers), artifacts predicted to belong to the same source or source area do have a tendency to group together (those assigned to Sherwan are found mainly in C1 and C4, to Painthal in C2 and to Prang Dera in C3).

Cluster analysis focusing solely on steatite artifacts from Harappa was necessary in order to gain a clear understanding of the compositional variability possessed that sub-assemblage. It is now possible to much better evaluate the distribution of those artifacts among the “main” clusters of the dendrogram generated in the CA of the full geologic and archaeological sets (Figure 7.17). To facilitate the examination of that dendrogram, the number for most of the Harappan artifacts appearing on it (Appendix 7.9) is preceded by the codes (C1 through C4) denoting the cluster that each belonged to in Figure 7.21.

On the full archaeological/geologic dendrogram (Figure 7.17 and Appendix 7.9) the artifacts that were members of C1 and C2 in Figure 7.21 are entirely encompassed in a large, closely related sub-cluster of “main dolomitic cluster #2” (MDC#2) that extends from Section G to Section K and joins at RDCC 4 in Section I. Within that sub-cluster, C1 and C2 artifacts do remain, more or less, distinct from one another suggesting that may represent different deposits or, *perhaps*, different outcrops or veins within a single deposit

(the latter possibility is discussed more fully below). The geologic samples encompassed in that same sub-cluster of MDC#2 include 19 of the 20 samples from the Painthal deposit but only eight of the 30 from the Sherwan zone. Recall that C1 was dominated by artifacts with a first PGM in one of the Sherwan deposits and about half of the artifacts in C2 were predicted to belong to the Painthal source with most of the rest assigned to the Sherwan zone. It could be that many of the C1 artifacts assigned to Sherwan actually belong to a source in the Jammu region. However, over half (11 of 20) of the geologic samples from the Daradar deposit are in the sub-cluster too as are six artifacts assigned to that deposit. This just serves to illustrate and remind that overlap for geologic sources is very much a concern at this level and so PGM assignments should be considered tentative.

Most (18 of 26) of the artifacts that had been in C3 group together in a small but closely related sub-cluster of, aptly enough, MDC#3, which runs from Section N to Section O and joins at RDCC 3. Ten artifacts in that cluster have the Prang Dera, Khyber Agency (LKPD) deposit at their first PGM and three others have it as their second PGM. Half of the geologic samples in that same sub-cluster are from that deposit and so it can probably be regarded as fairly strong association. Six of the remaining eight artifacts that were originally in C3 grouped with the C1 and C2 artifacts in the same large sub-cluster of MDC#2 described above. The last two C3 members, both of which were assigned to the Sherwan zone, grouped in a cluster with three Sherwan assigned members of C4 in a sub-cluster (in Section F) of MDC#2 different than the one described above.

All of the Sherwan assigned artifacts that had made up C4 (with the exception of the three members just mentioned) group in MDC#1 (section D and E). That cluster joins

at RDCC 6 but most of the artifacts in it are in a sub-cluster that joins at RDCC 2. Also in MDC#1 is H96/7467-658, which had been in the small branch of compositionally distinct artifacts at the bottom of Figure 7.21. Although the Teori (ATM) deposit in the Alwar District of southern Rajasthan is its first PGM, its second PGM is Sherwan Banda (SB) so it could be related to the other Sherwan assigned artifacts also now in MDC#1.

The artifacts that were not in one of the four defined clusters on the 140 Harappan samples dendrogram appear on the full archaeological/geologic set dendrogram in both expected and unexpected ways. The BMAC steatite wig (H98/8668-2) falls in the "Main ultramafic cluster" (MUC) in a small sub-cluster with geologic samples from the Sakhakot-Qila ophiolite. There can now be little doubt that this object is made from stone of ultramafic origin (possibly from the deposit it assigned to) and is very different from the steatite typically used at Harappa. The other artifact that had been predicted to belong to an ultramafic source – H97-7784-27, now is an outlying member of a small sub-cluster in MDC#2 (Appendix 7.9 Section G) made up of samples from the Degota deposit (DGT) in northern Rajasthan and the Khanda deposit (GPM) in Gujarat. This artifact could actually be an unusual dolomitic steatite with ultramafic properties (high Co and Cr concentrations). However, the opposite may be true as it lies nearby two of the samples from ultramafic sources (from ZUN in the Muslimbagh ophiolite) that in CDA and CA have been shown to overlap with the dolomitic sources. The final two artifacts that were compositionally distinct outliers – H2000/9445-1 (assigned to ANB in the Alwar District) and H2000/9840-8 (assigned to Sherwan Banda), both appear in MDC#3 but are still very distinct from both one another and the other artifacts in that cluster.

Before shifting focus from the evaluation of the CA results to their interpretation (in the next sub-section), a few final observations need to be related about the way in which the geologic samples and the artifacts are distributed on the dendrogram of the full geologic and archaeological steatite sets (Figure 7.17 and Appendix 7.9).

To begin with, steatite artifacts (from Harappa and the other sites) tend to group in clusters of cases that are far more closely related to one another than most groups of geologic samples collected from individual steatite deposits. For example, in Section H and I there is a cluster containing 28 artifacts that are all joined at RDCC 1. In other words, they are as compositionally similar to each other as cases depicted on the dendrogram can possibly be. Twenty-five members of that cluster were predicted to belong to one of the Sherwan zone deposits (and the three that were not had second PGMs in that zone). There are many other groups of artifacts like that one. Figure 7.22 is a table listing all of the artifact clusters with ten or more members that join in each of the first three RDCC levels. I chose to define clusters of ten both because it was a good round number and it was close to the average number of geologic samples analyzed per source (n = 11.9). Well over half

Figure 7.22: Artifact clusters with or more 10 members in each of the first three RDCC levels on the full archaeological/geologic set dendrogram (Figure 7.17)

	RDCC 1 # of members (section/s)	RDCC 2 # of members (section/s)	RDCC 3 # of members (section/s)
Clusters	10 (G) 19 (H) 28 (H & I) 18 (I) 22 (J & K)	10 (D) 10 (G) 11 (G & H) 19 (H) 47 (H & J) 11 (J) 24 (J & K) 11 (N)	10 (D) 10 (G) 77 (G to J) 11 (J) 25 (J & K) 20 (N & O)
total	**5 clusters / 98 artifacts**	**8 clusters / 143 artifacts**	**6 clusters / 153 artifacts**

of the 177 cases in the archaeological set are encompassed in just five clusters at RDCC 1. At RDCC 2, more than four-fifths of the artifacts group together in just eight clusters. One large cluster containing 77 artifacts and five smaller ones are formed at RDCC 3.

To appreciate just how closely related large groups of steatite artifacts are to one another it is only necessary to compare them to the clusters formed by geologic samples from individual deposits. For instance, the 20 samples collected from Prang Dera (PD) in the Khyber Agency are distributed widely across dendrogram (from section G to section N). The various sub-clusters they appear in do not join into a single cluster until RDCC 16. That level of similarity (or dissimilarity) is typical of the geologic deposits in the dataset. Figure 7.23 is a table in which the 37 deposits are listed according to the RDCC level at which all of their members are joined in a single cluster. The average level at which the

Figure 7.23: Rescaled distance cluster combine (RDCC) values at which all samples from a given geologic deposit can be encompassed into a single cluster on Figure 7.17.

RDCC	**1**	**6**	**7**	**8**	**9**	**11**	**13**	**16**	**25**
Geologic source	RDV RSH	KOT	RKA	JAMPT	ZTT CHT DMK LBW1 RKG RMP RSB	PD	JKK	LKPD SB RSA	ANB ASN ATM BESH DGT GPM JJC JJG RDP RRA SC SKK UB USK US LBW2 RST ZTAK ZUN RRD

deposits form complete clusters is 17.8. The only sources whose members all join at RDCC 1 are the Dev Pura (RDV) and Khadi Ghati (RSH) deposits of southern Rajasthan. None of the others join into a single cluster until RDCC 6 or higher. The majority of the deposits in the geologic set (20 of the 37) do not, in fact, completely join until RDCC 25.

The differences in how steatite artifacts tend to cluster versus how samples from steatite deposits typically cluster are striking. The way the latter are dispersed on the dendrograms actually helps to clarify why certain artifact provenience assignments (PGMs) may be distributed in the manner that they are. For example, on both the full sets dendrogram (Figure 7.17 and Appendix 7.9) and on that for the 140 artifacts from Harappa (Figure 7.21 and Appendix 7.10), artifacts assigned to the Sherwan zone appear in every major cluster (except the MUC on Figure 7.17). Some of those clusters (C4 on Figure 7.21 and MDC#1 in Figure 7.17) are quite distinct from most others. This *could* indicate that the artifacts making them up, although they have the same PGMs as those in the other clusters, are from a different source(s). However, it is now clear that samples from most of the individual geologic deposits possess a significant degree of internal geochemical variability and are dispersed in a way not unlike the PGMs. It is very possible, therefore, that artifacts having the same PGM assignments but appearing in different clusters are indeed actually from the same geologic source. Still, the possibility that the compositionally distinctive Harappan artifacts comprising C4 in Figure 7.21 and again appearing (mostly) in MDC#1 on Figure 7.12 (and later in section D of Figure 7.27) are from a source different from that of the other archaeological samples in the set should be kept in mind as discussions of steatite acquisition take place in the next section.

The different clustering patterns for the archaeological and geologic steatite samples have also provided a potentially important insight into the exploitation and use of that variety of stone in antiquity. The large clusters of closely related steatite artifacts could conceivably represent groups of raw material from single geologic occurrences. However, as has just been discussed, few geologic deposits in the dataset even approach having the same level of compositional homogeneity as exhibited by the artifact clusters. I therefore submit that those clusters possibly represent raw material exploited from a very restricted area *within* an individual steatite occurrence, such as a single vein, pit or mine.

When I visited a steatite source for this study I had two objectives: 1) to collect examples of Harappan-quality stone and 2) to obtain the widest range (in terms of spatial distribution and macroscopic appearance) of that material as possible so as to document the geochemical variability of the deposit. With regard to the latter objective, I seem to have succeeded (judging from the dispersed geologic samples and the overlap between sources). The closely related groups of artifacts in the archaeological set may indicate that when Harappans (or their suppliers) visited a steatite source their objective was to acquire a specific kind of material, rather than just any seemingly good-quality stone found there. If they had been obtaining a wider variety of material from across a deposit or zone then the clustering patterns among the artifacts might be expected to look more like those of the geologic sources. Although we cannot be certain that of the all artifacts in a closely related cluster actually came from one source, the exploitation of a very specific kind of stone would fit with what I argue to have been a primary concern for Harappan craftspeople, which was the acquisition of steatite that becomes white when heat-treated.

Interpretation of the results

The 619 unfired steatite artifacts and geologic samples constitute the most complex dataset in this dissertation. The painstaking series of analyses and evaluations detailed in the preceding section were necessary in order to get to the point where the predicted group memberships of artifacts could be confidently interpreted and used to form responses to the lines of inquiry outlined in Chapter 1.

Figures 7.24 and 7.25 are tables designed to facilitate the detailed temporal and spatial examination of the steatite artifacts from at Harappa. They were created using the 138 PGMs from resulting from the "11 dolomitic sources" CDA analysis (Figure 7.19 / Appendix 7.1 column 8) and the two PGMs for Harappan artifacts from the ultramafic parent-rock CDA (Figure 7.16 A / Appendix 7.1 column 7). When the results of the two analyses were combined, a total of 13 geologic deposits had artifacts assigned to them. These deposits are listed alphabetically by source code (see Appendix 7.2 column 4) in Figure 7.24 and are cross-referenced with the macroscopic types and general contexts (mound and period) of the artifacts assigned to them (surface and off-mound contexts were not noted this table). Type and contextual data for the artifacts are also found on the reproduction of the 140 Harappan artifacts CA dendrogram (Appendix 7.10), which is also referred to in this examination. Several of the source codes are followed by an asterisk and the notation "actually Sherwan?" For reasons explained in the preceding section, I consider it probable that the handful of artifacts assigned to southern Rajasthan and Uttaranchal are actually from one of the deposits in the Sherwan zone. Those assigned to the Daradar (PD) deposit could be as well and so I have noted them along with the others.

Figure 7.24: The 13 PGMs for the 140 steatite artifacts from Harappa and their type / contextual associations (surface and off-mound contexts not noted). See text and Appendix 7.2 for source codes.

Source (# of artifacts)	**Types**	**Periods**	**Mounds**
ANB (2)	F, G	3B, 3C	AB, F
ATM (2) 1*actually Sherwan?	A	1*	AB
JAMPT (14)	A, B, C, E	1, 2, 3A, 3B	AB, E
KOT (1)	F	3C	F
LBW1 (1)	A	3A	AB
LKPD (13)	A, B, C, F, G	2, 3A, 3B, 3C, 4/5	AB, E, ET, F
PD (6) *actually Sherwan?	A, B, C, E, F	2, 3B, 3C	AB, E, ET, F
RDP (2) *actually Sherwan?	A, D	2, 3C	AB, ET
RSA (2) *actually Sherwan?	A, E	3A, 3C	AB, F
SB (41)	A, B, C, D, E, F, G	2, 3A, 3B, 3C	AB, E, ET, F
SC (16)	A, B, E, F, G	2, 3A, 3B, 3C, 4/5	AB, E
SKK (38)	A, B, C, D, E, F	2, 3A, 3B, 3C	AB, E, ET, F
USK (2) *actually Sherwan?	A	3A	AB

Figure 7.25: Spatial and temporal distribution of the PGMs for the 140 artifacts from Harappa

Period → *Mound ↓*	**1**	**2**	**3A**	**3B**	**3C**	**4/5**	**surface & disturbed**	*total*
F	*not present*	*not present*	*not present*	PD* SKK	ANB KOT LKPD RSA* SB x7 SKK x2	*not sampled*	*not sampled*	*15*
AB	ATM* JAMPT	JAMPT x6 LKPD PD* RDP* SB SC x 5 SKK x 2	JAMPT LKPD x2 LBW1 RSA* SB x2 SC x3 SKK x9 USK x2*	ANB JAMPT SB x3 SC x4 SKK x2	SB SC	LKPD SC	ATM SC SKK	*58*
E	*not sampled*	JAMPT	JAMPT x2	JAMPT x2 LKPD x2 SB x1 SKK x2	LKPD x3 PD* SB x5 SC SKK x5	*not sampled*	JAMPT LKPD PD* SB x 6 SKK x3	*37*
ET	*not present*	*not present*	*not present*	SKK	LKPD x3 PD x2* RDP* SB x6 SKK x7	*not sampled*	SB x3 SKK	*24*
cemetery & off mound	*n/a*	*n/a*	*n/a*	*n/a*	SB x4	*n/a*	SB SKK	*6*
total sampled	*2*	*18*	*23*	*21*	*53*	*2*	*21*	***140***

In Figure 7.25, the PGMs for all 140 artifacts from Harappa are cross-listed by the area and period from which they were recovered. Multiple artifacts from one source are indicated by a “times” sign and number (e.g., SB x 4 = four artifacts from Sherwan Bandi).

Type associations

Before beginning the discussion of steatite acquisition at Harappa, the macroscopic categories or “types” (Figure 7.4) that were used to classify unfired artifacts at the site are briefly considered in relation to the CDA predicted group memberships and the CA results. As I began to suspect while still collecting geologic samples for this study, there appears to be no clear relationship between the various “types” of raw steatite and sources of that stone (at least those that are in the geologic dataset). The second column of Figure 7.24 shows which of the seven types (A through G) are associated with each of the 13 deposits to which artifacts were assigned None of them appear exclusively with any one source or source area (such as the Sherwan zone). In fact, each is associated with at least three different deposits. Artifacts of the same “type” also seem to be, for the most part, highly variable compositionally. A perusal of the type codes listed next to terminal ends of the Harappan artifact dendrogram (Appendix 7.10) indicates that, aside from one or two minor areas (such as where six Type F artifacts fall together in Cluster 2), each type is distributed widely among the four clusters. Of course, samples from most of the geologic deposits are similarly distributed and so it is *possible* that artifact of a particular “type” come from the same source. Even so, these findings suggest it is very unlikely that the macroscopic appearance of unfired steatite artifacts (at least of those from Harappa) can provide reliable information about their geologic provenience.

Addressing the three lines of inquiry

The CDA and CA results are now brought to bear on the three lines of inquiry – the first being: *With whom were residents of Harappa interacting when acquiring steatite? What was the extent of those inter-regional interaction networks during different periods?*

The results of this study indicate that acquiring of most of the steatite used at Harappa would have entailed either direct or indirect interaction with non-Indus Civilization cultures dwelling in the highland region 330 to 445 km north of the city. Around 89% of the 140 steatite artifacts analyzed were predicted to belong to one of seven geologic sources in that region (JAMPT, KOT, LKPD, PD, SB, SB or SKK). When those artifacts that were likely misclassified as belonging sources in southern Rajasthan and Uttaranchal are factored in, the percentage is almost 95%. These percentages, and the others reported in this section, were generated by averaging the first PGMs of the four reported CDAs (listed in the last four columns of Appendix 7.1). When I discuss the provenience of specific artifacts I am relying on the PGM made from the "11 dolomitic sources" CDA unless otherwise stated.

Of the artifacts assigned to "northern" sources, around 69% (61% of the total from Harappa) appear to be most closely related to steatite from occurrences in the Sherwan zone of the Hazara District (SB, SB and SKK), which are around 50 to 60 km north-northwest of the Kot Dijian settlements of Hathial and Sarai Khola. Among these is the unfinished steatite stamp seal (H96/7257-46) pictured in Figure 7.5 A. Approximately 13% were predicted to belong to the Painthal deposit in Jammu, which is just 25 km from the Early Harappan and Harappan site of Manda. The bead blanks (H2000-2301-176 & 177)

pictured in 7.5 C & D are assigned to this source. Another 11% of the artifacts assigned to "northern" sources had first PGMs of the Prang Dera source, Khyber Agency. However, it may be that around half of those may actually belong to the Sherwan zone as *perhaps* some or all of the roughly six percent assigned to the Daradar, Kurram Agency source do. The final artifact from Harappa assigned to a "northern" source is the BMAC steatite wig (Figure 7.5 E). Its first PGM, both when compared to the full geologic set and just to the ultramafic deposits, is the Sakhakot-Qila ophiolite (KOT) in the Mohmand Agency, FATA.

A few dozen sites belonging to the cultural phase that Stacul calls (1992, 1994) the "Inner Asian Complex" and that Possehl refers to as the "Northern Neolithic" (1999: 542-553) have been identified across the same general region where many of the "northern" steatite deposits are found. It is with the highland-dwelling farmers and pastoralists of this culture that residents of Harappa would have interacted with, either directly or indirectly, to obtain much of their steatite. Kot Dijian items found at Northern Neolithic sites in the Swat (Stacul 1987) and Kashmir (Saar 1992) valleys provide clear evidence for contacts between those highland and lowland peoples. Although the nature of those contacts is not known, there are several possible scenarios with regard to steatite acquisition.

1) Northern Neolithic peoples could have been the ones who extracted steatite and transported it to the Punjab; perhaps along with some of the other raw materials that I later show also likely came from sources in the north such as vesuvianite-grossular (Chapter 9), alabaster (Chapter 10) and lead ore (Chapter 12). Although they primarily inhabited the mountain valleys of northern Pakistan and India, it is certainly not out of the question that they may have traveled to the south. Possehl reports (1999: 548) having identified

Northern Neolithic sites near Leiah in the Thal Desert of the western Punjab. However, no items clearly related to that culture have yet been discovered at Harappa.

2) Northern Neolithic peoples might have mined steatite and then transported it only as far as the nearest Early Harappan or Harappan settlement. From there, the raw material could have been moved through internal Indus trade networks to sites in the south like Harappa while Indus trade goods (carnelian beads and Kot Dijian-style ceramics) could have been acquired and brought northward to the Northern Neolithic sites where they have been found. Hathial, Sarai Khola, Manda, Ropar and other settlements in the foothills and/or on the plain at the base of the Himalayas were certainly well-positioned to be nodes where this type of exchange between highland and lowland cultures could take place. However, it has never been established if such sites actually functioned as trading outposts.

3) A person or a group from Harappa (or another Early Harappan/Harappan site) could have traveled to the northern highlands and extracted steatite themselves from one of the sources found there. This still would have entailed some form of interaction with local populations. Importantly, it also would have permitted them to judiciously select raw material having properties that they (or their fellow Harappans whom they were supplying) desired. As I suggested above, the groups of steatite artifacts that are highly related to one another compositionally may represent stone extracted from the same vein, pit or mine shaft within a larger individual occurrence or zone. I also suggested that this focus on material from a restricted area (rather than from an entire deposit), if it is genuine, is probably indicative of the desire by Harappan craftspeople to acquire a very specific kind of steatite that turns white upon being heated. The macroscopic appearance of raw steatite

does not provide any indication of what color it will become after being fired (*personal observations* discussed below). Therefore, the identification of areas where white-firing stone occurs within a deposit almost certainly would have involved some amount of experimental heating. Northern Neolithic peoples appear to have used very little steatite themselves (Pande [2000] reported that just eight of the 1488 beads recovered at Burzahom are made from steatite) and, as far as we know, none were heat-treated. Although this does not necessarily mean that those northern peoples would have been unable identify and exploit bodies of white-firing steatite, Harappans, with their advanced pyrotechnological capabilities and intimate knowledge of this variety of stone, were likely far more adept at it.

The scenarios above are not the only ones that could account for how raw steatite from “northern” sources was acquired by craftspeople at Harappa. Variations of all three could have taken place, either simultaneously or at different times. Perhaps an unknown third party was involved (Scenario #4). However, short of discovering artifacts at a mining site that are clearly associated with a cultural phase (Harappan or some other one) it is almost impossible to do more than speculate about who actually did the work of extracting the stone. Issues relating to exchange between highland and lowland cultures at settlements that may have been trading outposts cannot be addressed until further question-oriented excavations are conducted at such sites. With regard to the transportation of the stone, we really can talk only about whether or not the sources that appear to have been exploited are internal or external to the area encompassed by Early Harappan/Harappan cultures. Even then we must be cautious because, as Smith has pointed out (2005), models of cultures as bounded, homogenous socio-political entities are often based upon cartographic illusions.

Putting aside interpretive considerations for the moment, the above results constitute clear and compelling evidence for interaction between residents of Harappa and peoples in the highlands to the north of the site, especially those in the Hazara District and Jammu. It is unlikely to be a coincidence that (Late) Kot Dijian and/or Harappan sites are found in the same general vicinity as steatite deposits in those regions. Some degree of interaction with groups in the Kurram and Khyber agencies is also indicated. However, there are sources in Hazara (like the Khangar Dhaka deposit in the Sherwan zone) and in Jammu (multiple deposits in the vicinity of Vaishno Devi) that, when eventually analyzed, could be found to be the actual sources of some or all of those artifacts assigned to deposits in the FATA.

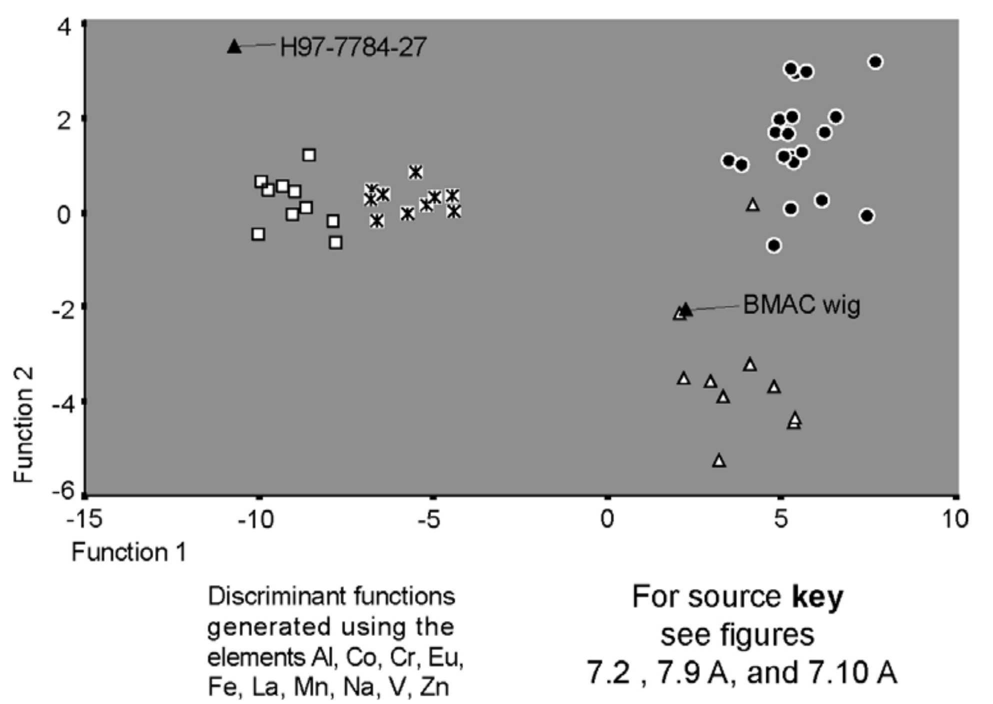
On that note, it is important to again acknowledge that the PGMs made here could change, perhaps drastically in some cases, as samples from more deposits are incorporated into the geologic dataset. In this regard, artifacts to be mindful of in future analyses include those making up the compositionally very distinct cluster number four (C4) in the 140 Harappan artifacts dendrogram (Figure 7.21). All are assigned to one of the Sherwan deposits but they do not join the other artifacts assigned to that zone until RDCC 25 (this is also true of most of those same artifacts on the full sets CA dendrogram [Figure 7.21]). I have discussed above how it is possible for artifacts to be from the same source but end up in very different clusters. This could be one of those instances. However, in an upcoming dendrogram it is evident that "C4" artifacts are *somewhat* more closely related to a similarly distinct group of artifacts from the site of Mehrgarh than they are to most of the others from Harappa (Figure 7.27). There is the possibility, therefore, that they might have been derived from an unsampled deposit in Balochistan. Only future analyses will tell.

One final artifact that was initially predicted to belong to a deposit in the highland region north of Harappa remains to be discussed. It is the BMAC steatite wig from Period 3C, which is assigned to the Sakhakot-Qila ophiolite source. Its PGM is important for two reasons. Firstly, it supports the stylistic evidence that indicates the wig is a non-Harappan object by showing that it was created from ultramafic steatite – a type rarely used by Harappans. Just one other unfired steatite object at Harappa (or at least just one other among the 4.68% of the sub-assemblage that was analyzed) and only a few from any of the other Indus Tradition sites in the archaeological sample set are composed of material of ultramafic origin. Secondly, this finding provides (or can provide) information about the avenues through which Harappans interacted with the Central Asians who probably made and used the wig. Evidence from Mehrgarh Period VIII and elsewhere suggests that BMAC peoples were entering the Sindh region via central Balochistan around the turn of the first millennium BC (Jarrige 1991a; Parpola 2005: 267). However, there are other routes from Central Asia and Afghanistan along which they could have traveled into the Indus Valley. If the wig is actually made from Sakhakot-Qila steatite then it would suggest that one of those alternate routes was through Peshawar Valley via one of the many passes (Khyber, Malakand, Bajaur) that connect it with regions to the west and north.

It is possible, however, that the wig is made of steatite from a different source. When it is compared to a refined geologic set (Figure 7.26) that includes the deposits that were its original first and second PGMs – Sakhakot-Qila (or KOT – 1st PGM) and Zhob Tor Tangi (or ZTT – 2nd PGM), it is re-assigned to its initial second PGM. So the wig *could* actually be from an ultramafic source in north Balochistan. This would still support

the interpretation that it is a non-Harappan object although it might now indicate that BMAC peoples were indeed entering the Indus Valley via Balochistan rather than the NWFP. It is also possible that the steatite used to make the wig comes from a different source altogether, perhaps one nearer to the BMAC homeland, which, of all of the deposits in the geologic set, happens to be compositionally most similar to the ones at Sakhakot-Qila and Tor Tangi. The INAA results for the wig indicate that clearly the place to search for that deposit would be in an ultramafic formation, probably an ophiolite.

Figure 7.26: The two ultramafic steatite artifacts from Harappa compared to select ultramafic sources



On average, only around five percent of the 140 steatite artifacts analyzed from Harappa appear as if they might be composed of raw material from sources outside of the region to the north of site. One of these is artifact H97-7784-27 – a yellowish gray (Type A) sawn fragment from Period 3A workshop debris exposed in Trench 42 on Mound AB.

It is the only steatite object analyzed from Harappa other than the BMAC wig that appears to be of ultramafic origin. Although it does not resemble the distinctive type of green steatite with black spots that is so well-known in Pakistan today, it was predicted to belong to the same group of samples of that stone that were obtained from the Duddo mine (LBW1) in the Wayaro area, Las Bela District, Balochistan. Recall that this deposit is located less than 20km from Bakkar Buthi where there is an Indus Civilization phase equivalent to Period 3A and 3B at Harappa (Franke-Vogt et al. 2000: 199) and so it might then have been directly accessible to the Harappans living there.

There is, however, a good possibility that the raw material this artifact is composed of did not come from the exact deposit to which it has been assigned. When it is compared to a refined geologic set (Figure 7.26) that includes the deposits that were its original first and second PGMs – Duddo mine (or LBW1 – 1st PGM) and Thaddi mine (or LBW2 – 2nd PGM), it is re-assigned to the Thaddi deposit, which is only about 5 km away from Duddo. Note, however, that the artifact appears distinct (plotting away from) from both deposits. It may be that it was quarried from one of the many old pits and worked shear zones that I observed in the area rather than the modern mines. Or it might be from another occurrence. Although I have found no references to other deposits in the geologic or historic literature, the Las Bela ophiolite extends from the Wayaro area northward over 100 km, past Kulli culture settlements like the Edith Shahr complex (Fairservis 1975) and Nindowari (Casal 1966). The artifact could conceivably be from a geologically related steatite occurrence that was nearer to the ancient peoples of those sites. In any case, of all of the ultramafic deposits in the geologic set it is still most closely related to those from southern Balochistan.

Between four and ten artifacts from Harappa were, depending on the CDA results, predicted to belong to steatite sources in the Jhunjhunu and Alwar districts of northern Rajasthan. Like those originally assigned to Uttaranchal and southern Rajasthan deposits, many have second PGMs in one of the sources to the north of the site and could be, in fact, from that region. Artifact H96/7531-16 – a small fragment from Period 1, is one of these that are *perhaps* a misclassified outlier. It is noted "*actually Sherwan?" on Figure 7.24.

A few artifacts that were predicted to belong to a northern Rajasthan deposit appear on the CA dendrograms to be compositionally distinct from the majority of the other artifacts in the set, which is say that they are very different from most of the ones assigned to the Sherwan zone and other "northern" sources. The cylindrical bead (H96-7467-658) made of black steatite pictured in Figure 7.5 B was one of these. Although in the full set CDA it was assigned to the Sherwan zone, in the later refined 11 dolomitic sources CDA it was predicted to belong to the Teori (ATM) deposit in the Alwar District. Other similarly distinct artifacts include fragments H99/8760-77 and H2000/9445-1, both of which were assigned to the Nangalhari-Bairaswas zone (ANB). These, and the few others like them, may indeed be from deposits in northern Rajasthan (including some in Jhunjhunu). The presence of steatite at Harappa that is genuinely from that region would constitute evidence for interaction with peoples of the Ganeshwar-Jodhpura complex. However, it is possible that some or all of these artifacts actually are from a source or sources that are not in the geologic set. On the full sets CA dendrogram (Appendix 7.9), the artifacts noted in this paragraph, although assigned to northern Rajasthan deposits by CDA, do not actually cluster with or nearby any geologic samples from that region.

Next, the PGMs for the Harappan artifacts are used to address the question: *Did the patterns of steatite acquisition exhibited by residents of Harappa change over time?*

Based on a preliminary study conducted in 2003, I reported (Law 2005a: 118-119) that a significant diachronic shift in source utilization was evident in Harappa's unfired steatite artifact assemblage. I had interpreted four major clusters on a CA dendrogram to be roughly equivalent to individual sources or source areas. Two clusters, one of which was composed largely of artifacts predicted by CDA to belong to the Sherwan (Hazara) zone and the other of artifacts assigned mostly to the Prang Dera (Khyber) deposit, seemed to have been utilized mainly during the Early Harappan period. The two other major clusters, which at the time I thought might have represented sources in Jammu that had not then been analyzed, seemed to have been exploited mostly during the Harappan period.

Based on the CDA PGMs and the CA dendrograms produced for the current study, which involved additional archaeological samples and a substantially enlarged geologic dataset, I have concluded that diachronic changes in steatite acquisition patterns at Harappa are not nearly as significant as they were reported to be in 2003. In fact, I would now characterize source use as remarkably consistent throughout most, if not all, of the site's prehistoric sequence. There were no increasing or decreasing trends in the exploitation of certain sources such as are evident for grindingstone (Chapter 5). Nor was there any dramatic shift in material source/type use like that which is evident for chert (Chapter 6). Although there were some changes over time, for the most part they were very minor. The steatite assemblage is dominated in every period by raw material from sources north of the site. Thus, the acquisition networks appear to have been stable and mostly unidirectional.

Steatite acquisition through time can be examined using figures 7.24 and 7.25. Deposits in the Sherwan zone (SB, SC and SKK) were being accessed at least by Period 2 (some perhaps as early as Period 1 – discussed below) and they continued to be the primary sources of the stone through Period 5. The use of raw material from the Khyber Agency (LKPD), although evidently much less intense, follows the exact same temporal pattern. Steatite from Jammu (JAMPT) was used steadily from Period 1 through Period 3B. Its apparent absence in Period 3C simply may be due to it being missed in sampling. The 53 artifacts analyzed from that period represent only a 3.81% sample of the temporal sub-assemblage of material (Figure 7.6 B). However, it could be that acquisition of steatite from Jammu (or at least from the Painthal deposit) actually ceased after Period 3B. Regardless, all of these steatite provenience associations demonstrate that residents of Harappa were involved in early and sustained interaction networks with peoples (either Harappan or non-Harappan) dwelling in the region to the north of the site.

Steatite artifacts predicted to belong to deposits in Uttaranchal, southern Rajasthan and even some of those assigned to northern Rajasthan and the Kurram Agency, are very likely misclassified outliers of the Sherwan zone. Their firsts PGMs are left unchanged on figures 7.24 and 7.25 but their doubtful statuses are noted with asterisks. One artifact (H96-7531-16) with a questionable PGM is from Period 1. It was predicted to belong to Teori (ATM) in northern Rajasthan but *may* actually be a Sherwan outlier as it was assigned to that zone in the regional-level CDA. Even if it is actually from northern Rajasthan or another source area outside of northern Pakistan/India, Harappa's raw steatite assemblage during the Ravi Phase was, regionally speaking, as diverse as it ever would be.

The remaining few steatite artifacts from sources other than the main dolomitic ones in the north are found during Harappa's urban phase (Period 3). In addition to the BMAC wig and the artifacts that may be from northern Rajasthan, there is the ultramafic fragment from the Period 3A workshop on Mound AB that was predicted to be from the Wayaro area of southern Balochistan. The presence of steatite from this distant source (800 km southwest of Harappa) during Period 3A is not particularly surprising. At that time, Harappans were living in the vicinity (< 20 km away) of the deposit itself and marine shell (Kenoyer 1984b) and salted fish (Belcher 2003) were being transported from the nearby Arabian Sea coast. Steatite from southern Balochistan in a Punjab workshop is just another piece of evidence showing that the long-distance internal exchange networks characteristic of the Indus Civilization were firmly in place by that time. What is surprising is the rarity of this high-quality material. The 18 fragments analyzed from the Period 3A workshop represent an almost 10% sample of the steatite recovered in it. Had craftspeople there used raw material from Wayaro to a significant degree then chances are that at least a few more examples would have been sampled and identified. There is also the question of why, evidently, urban phase Harappans did not continue to acquire and use this kind of steatite. As is shown in my provenience study of lead artifacts (Chapter 12), raw materials from the southern Balochistan region were being transported to Harappa through the end of Period 3C. The reason why Wayaro steatite did not continue to be used probably lies with the physical properties of the material rather than the distance to its source. Although it is excellent stone for carving and sawing, it will not fire to the white color that was preferred by Harappan consumers of steatite items (discussed in the final section of this chapter).

The final question is: *Did synchronic variations in patterns of steatite acquisition exist between groups of people living in different habitation areas at Harappa?* The answer to that question is: evidently not – at least not any major ones. By and large, craftspeople at Harappa all seem to have had access to the same sources of steatite regardless of where they lived and worked within the settlement. When the PGMs on figures 7.24 and 7.25 are considered on the regional level, the chronological sub-assemblages for all mounds either entirely (usually) or predominately (occasionally) consist of artifacts from the broad source area 330 to 445 km north of the city. That is, of course, to be expected given that about 95% (if potential misclassifications are factored in) of the artifacts analyzed were assigned to deposits in that region. When source use is considered on the level of individual deposits and zones, there does at first appear to be some variation among mound sub-assemblages during the certain periods. However, most synchronic differences can be explained by some form of sampling bias. The very small sample sizes (just one or two artifacts each) for Mound E during periods 2 and 3A, mounds F and ET during Period 3B and Mound AB during Period 3C, almost assuredly do not capture the full range of raw material sources used in those areas at those times. For example, on average, around 16 artifacts each were sampled from the Period 3C levels of mounds F, E and ET. Six different deposits are represented among the artifacts on each of those mounds. Only two deposits are represented on Mound AB. I strongly suspect that when the Period 3C sample from Mound AB is eventually brought up (from its current size of two) to the level of the other mounds its assemblage will appear just as diverse as theirs. Also, the reason that some chronological mound sub-assemblages do not contain artifacts

assigned to the Prang Dera (LKPD) source, which, overall, is widely distributed both temporally and spatially, is likely because of that deposit's low (≈ 11%) representation among the total analyzed assemblage. Artifacts having that PGM were fewer and more likely to have been missed in sampling. Ultimately, it comes down to this – assemblages in areas where a good-sized sample was obtained are fairly diverse in terms of their PGM compositions while those in areas where a small sample was obtained are not. Rather than interpret the differences as possibly genuine, I provisionally consider steatite source usage across Harappa to have been, more or less, synchronically consistent.

Having said that, the artifacts assigned to deposits outside of the "northern" region do provide some indication that craftspeople working in certain parts of Harappa might have had access to sources of raw material apart from those used by most other residents of the site. However, because such artifacts are so few in number, they must be interpreted cautiously. For instance, it would be a considerable stretch to argue that residents of the mounds where steatite fragments assigned to northern Rajasthan were recovered had exclusive access to and/or somehow controlled the raw material from that region, even if such artifacts might have been found only in the areas where they lived/worked. There are simply too few of them to confidently make such statements. Still, a close examination of artifact PGMs and their contextual details listed in Appendix 7.1 suggests that there might have been areas of the Harappa where, at certain times, some of the rarer kinds of steatite were used to a fairly significant degree. One of these areas is Mound F during Period 3C. In Trench 41, three fragments (H99/7636-8, H99/7637-32 and H99/7638-1) recovered from a group of Period 3C rooms adjacent to the city wall are possibly from northern Rajasthan

even though they were not assigned to that region in the "11 dolomitic sources" CDA (in most of the other CDAs the three were assigned to one of the Jhunjhunu deposits). Not far away in Trench 43, a fragment predicted to belong to the Nangalhari-Bairaswas (ANB) zone was also found. In total, 13 of the 63 unfired steatite artifacts recovered from Period 3C levels of Mound F were analyzed and, of those, four might be from a source in northern Rajasthan. If this is an indicative sample of the mound then perhaps around one-quarter to one-third of the steatite acquired by craftspeople working there might have come from that region 400 to 500 km southeast of the site. Recall from Chapter 5 that it was also on Mound F where most of the Delhi quartzite (from outcrops 75 to 125 km directly north of the northern Rajasthan steatite sources) was being used during Period 3C (Figure 5.13). These results for steatite artifacts could constitute an additional piece of evidence indicating that, of all residents at Harappa, people in this part of the site had slightly stronger trade relations with groups in the eastern part of the Greater Indus region.

Overall, however, I would characterize the synchronic patterns of steatite acquisition at Harappa as being similar to those evident for chert during the site's urban phases. For the most part, everyone had access to and was mainly using raw material acquired from the same broad source area (the "northern" region for steatite and the Rohri Hills for chert). Within that region, multiple deposits were being exploited but one zone or deposit in particular (the Sherwan zone for steatite and the Rohri town deposit for chert) seems to have been the source for the majority of the stone used. Raw materials from other source regions (northern Rajasthan for steatite and the Mohmand Agency for chert) may have sometimes acquired, but only infrequently and/or in very minor amounts.

Unfired steatite artifacts from seven other sites

In this sub-section, the unfired steatite artifacts from Mohenjo-daro, Mehrgarh, Nausharo, the "unknown" Loralai site, Gola Dhoro, Nagwada and Tepe Hissar are examined. Before focusing on the CDA results for each site individually, I present and discuss a CA performed on the entire archaeological set of 177 artifacts. This was conducted in order to first get a clear understanding of how compositionally similar or dissimilar the steatite artifacts from the seven sites were to the kinds of raw materials that were being used at Harappa. The CA dendrogram in Figure 7.27 was generated using the same complete linkage method that was employed to make the others in this chapter and its appendices. On it, the branches representing artifacts from the seven sites are noted using their two or three letter site codes (a key is provided on the figure). The branches representing artifacts from Harappa were left blank (it was too busy with artifact numbers). The specific numbers for all of the artifacts are found in the full size reproduction of the dendrogram (Appendix 7.11 sections A through D). Preceding the number for most of the artifacts from Harappa in Appendix 7.11 is one of four short codes in parentheses – "(C1)" through "(C4)." These codes denote the numbered cluster each one was originally a member of in the CA of just 140 artifacts from Harappa (Figure 7.21).

The 177 artifacts form two main clusters that split at RDCC 25. I first briefly discuss the distribution of the Harappan artifacts. The larger main cluster (to the left of the split) contains most of the artifacts from Harappa that had been in clusters C1 through C4 on Figure 7.21. The smaller main cluster (right) contains two former C4 artifacts as well as three had been outlier not assigned to clusters. Within the largest main cluster the Harappan

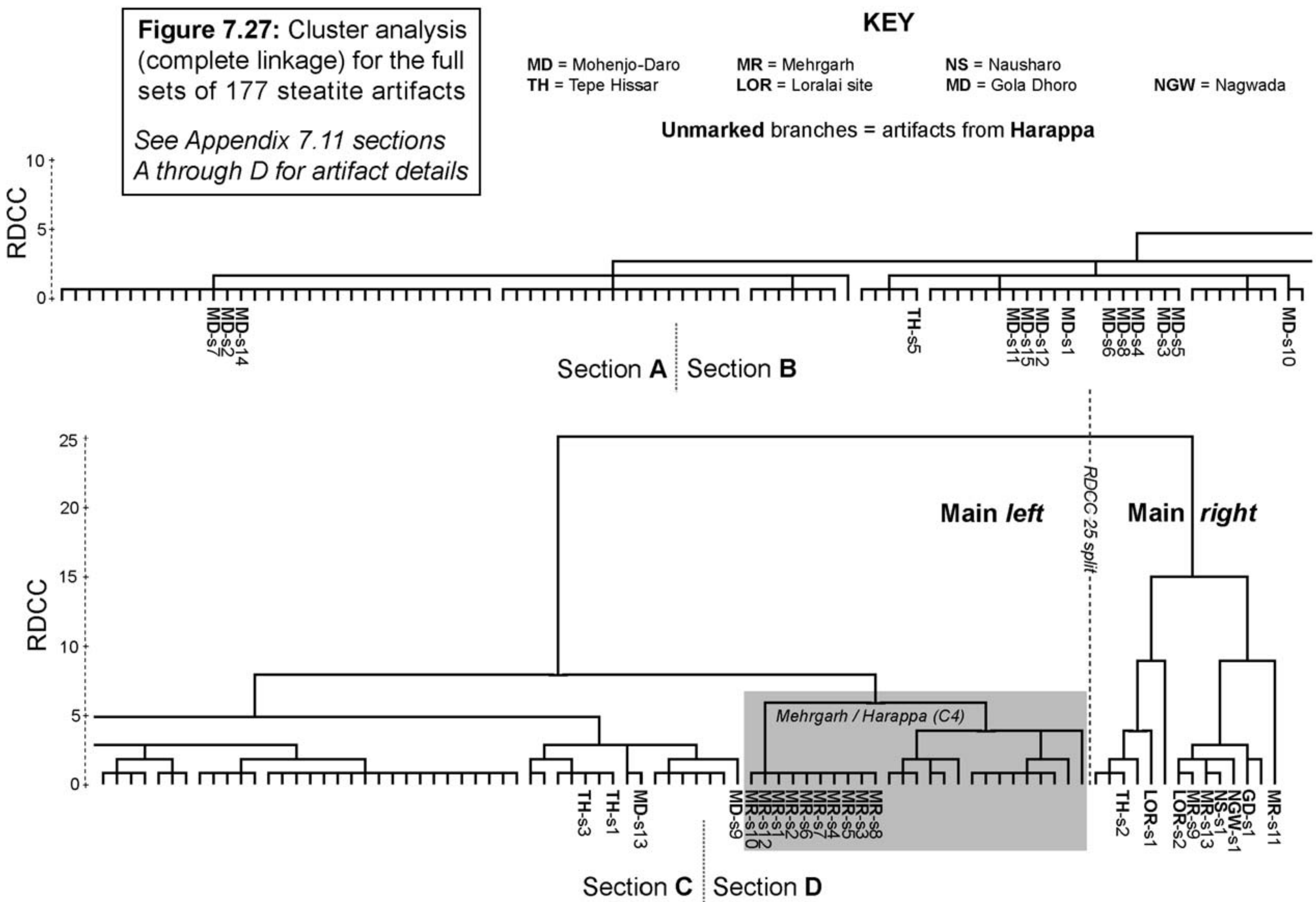


Figure 7.27: Cluster analysis (complete linkage) for the full sets of 177 steatite artifacts

See Appendix 7.11 sections A through D for artifact details

artifacts group in much the same way as they did in Figure 7.21. The one difference is that around half of those that had been originally been designated as C3 now appear with C1 artifacts while the other half still form a distinct sub-cluster of their own.

The manner in which the artifacts from the seven other prehistoric sites fall on the dendrogram is both interesting and informative. Compositionally, the 15 fragments from Mohenjo-daro (MD) are closely related to those from Harappa, which suggests that they may be from the same source or sources. Ten of the 13 artifacts from Mehrgarh (MR) group together in a very closely related (RDCC 1) sub-cluster that, within the larger main cluster, is set well apart from the Harappan artifacts. At RDCC 6, it joins another sub-cluster made up of Harappan artifacts, most of which had been in C4 on Figure 7.21. This Mehrgarh/Harappa-C4 sub-cluster is itself distinct from the other artifacts from Harappa (and Mohenjo-daro) in the larger main cluster. All of the Harappa-C4 artifacts have been predicted by CDA to belong to one of the Sherwan zone sources. However, their comparatively close association with the Mehrgarh artifacts raises the possibility that they *may* have actually been derived from a related deposit nearer to that site in Balochistan.

The majority of the remaining artifacts from the other sites are all members of the smaller main cluster on the right side of the RDCC 25 split. These appear to be composed of kinds of steatite that are very different from most of that used at Harappa. The exceptions are three of the four fragments from Tepe Hissar, which of all the artifacts in the archaeological set, seem to be compositionally most closely related to those from Harappa.

Informed by the results of the above CA, the artifacts from each of the seven other prehistoric sites are now examined using CDA. The parent-rock association of each artifact

was determined in the CDA of the full geologic and archaeological sets (Figure 7.14). Most of the PGMs discussed in the sub-sections below were generated during either the ultramafic parent-rock (Figure 7.16 A) or the dolomitic parent-rock (Figure 7.16 B) CDA. In a few instances select artifacts are compared to refined or selected subsets of samples.

Mohenjo-daro

Indus craftspeople working in both the DK-A and Moneer areas at Mohenjo-daro would appear to have been involved in the very same steatite acquisition networks as were their counterparts at Harappa. The first PGMs for nine of the 15 unfired steatite artifacts (Figure 7.7 A) analyzed from the site (listed in the second column of Appendix 7.5) are "northern" region sources – six are assigned to one of the Sherwan zone deposits and three are predicted to belong to the Daradar (PD), Kurram Agency source. Three of the remaining six artifacts have second PGMs in the Sherwan zone and so could be compositional outliers that came from that source. However, the first PGMs for five of those six is in a northern Rajasthan deposit (either ANB or ATM). One final artifact has a first PGM in a southern Rajasthan deposit (RDP) but it has a second PGM in a northern Rajasthan one (ANB) and, thus, may very well be a compositional outlier from the latter source area. The close compositional similarities exhibited by steatite artifacts from Mohenjo-daro and Harappa on the CA dendrogram (Figure 7.27 and Appendix 7.11) enables me to argue with a good deal of confident that those artifacts from both sites having the same PGMs are very likely from the same geologic sources. Later, I discuss artifacts from Mehrgarh that have also been assigned these same PGMs but which are quite clearly compositionally distinct from the Harappa and Mohenjo-daro artifacts.

Although the sample of artifacts from Mohenjo-daro is roughly one-tenth the size of that from Harappa, it nonetheless has permitted some interesting similarities and differences in steatite acquisition patterns between sites to be observed. To begin with, like at Harappa, the majority of steatite used at Mohenjo-daro seems to come from sources in the "northern" region and the majority of that majority is from the Sherwan zone of the Hazara District. However, whereas only around 5% to 10% (at the very most) of the analyzed artifacts at Harappa genuinely appear to have come from sources other than those in the north, up to 40% of the artifacts from Mohenjo-daro were likely acquired from deposits located in northern Rajasthan. Interestingly, this acquisition pattern for Mohenjo-daro much more resembles that of just Mound F at Harappa than it does of that entire site.

Also like at Harappa, it appears as if craftspeople working in different parts of Mohenjo-daro had access to the same sources of steatite. Artifacts assigned to the Sherwan zone, Kurram Agency and Alwar District deposits are found in both the Moneer and DK-A areas. Examples of steatite from two other source areas accessed by residents of Harappa – the Khyber Agency and Jammu, were not identified among the Mohenjo-daro artifacts. With regard to Jammu, the use of stone from the deposit analyzed in that region (JAMPT) seems to have ceased after Period 3B at Harappa. This could account for its absence on the surface of Mohenjo-daro, which is roughly equivalent to Period 3C. However, the absence of Khyber Agency and Jammu steatite may simply be due to the low sample size. On that note, it is important to recognize that the patterns of source usage suggested by the mere 15 samples from Mohenjo-daro could change dramatically when additional steatite artifacts are analyzed. The ones discussed here, thus, should be considered provisional.

The analysis of the Mohenjo-daro fragments has, nonetheless, generated new insights into Indus Civilization steatite acquisition networks as well as new questions about them. At this point it appears that residents of Mohenjo-daro did not acquire steatite from any of the three potential source areas nearest to their city (southern Balochistan, northern Balochistan or southern Rajasthan/Gujarat). One sample (MD-s13) did have a first PGM in southern Rajasthan's Deola (RDP) deposit but, like those artifacts assigned to this region at Harappa, I believe it to be a misclassified outlier. The results instead indicate that the majority of the Mohenjo-daro artifacts analyzed probably came from sources 800 to 900 km to northeast of the city in northern Pakistan while a large minority came from sources around 800 km due west in northern Rajasthan. That the steatite acquisition networks city residents were involved in could be that far-reaching is not at all surprising. Throughout this dissertation I show that raw materials such as chert (Chapter 6), agate (Chapter 8), limestone (Chapter 11) and lead (Chapter 12) were being transported, sometimes in bulk sizes, over equal or greater distances from the southern part of the Greater Indus region to the northern part. The Mohenjo-daro steatite artifacts constitute new evidence that an important variety of raw material was being moved, probably via the same trade networks, from the north and northeastern parts of the Greater Indus region toward the south.

These results, however, raise the question – Why did craftspeople at Mohenjo-daro (or their suppliers) not exploit much closer sources of seemingly good quality steatite, most especially the very nearest ones in Balochistan that were in the general vicinity of Indus Civilization settlements? In the case of the Wayaro sources of southern Balochistan it could just be an issue of timing and artifact recovery. Ute Franke-Vogt and others report

(2000: 199) that the Harappan occupation of Bakkar Buthi (the site nearest the Wayaro deposits) ended sometime prior to what is equivalent to Period 3C at Harappa – or the "Late Phase" at Mohenjo-daro. This fits well with the evidence at Harappa itself, which indicates some Wayaro steatite was brought to that site during Period 3A but not thereafter. If raw material from the same source was likewise acquired by residents of Mohenjo-daro only at that time then any remnants of it probably lay deeply buried beneath the city's "Late Phase" surface levels. But the question then would be – Why did Indus Civilization peoples (at Mohenjo-daro and Harappa) not continue to use steatite from southern Balochistan? Even if Harappans quit that region in the latter part of the urban period and, consequently, did not have had direct access to its steatite resources they likely could have still obtained the stone indirectly through interaction with the highland Kulli peoples dwelling there. I have concluded (and will argue in the final section of this chapter) that the reason why steatite from the Wayaro area and the other source regions closer to Mohenjo-daro were apparently not used by craftspeople at that site was probably because when it was heat-treated it did not transform into the white color they desired.

Mehrgarh and Nausharo

Although the 13 steatite artifacts from Mehrgarh (Figure 7.7 B) date to before the foundation of Harappa, their analysis has informed the current study by providing valuable glimpses of unsampled raw material sources that are probably located somewhere in the Balochistan and/or Afghanistan regions. One of those sources is represented by 10 of the 13 artifacts, which together form the closely related and highly distinct sub-cluster highlighted on Figure 7.27. Admittedly, I am making an assumption that all ten artifacts

are from the same deposit. They could be from ten different deposits in ten different geologic formations that just happen to be highly similar to one another compositionally. I very much doubt that is the case, however. The same ten artifacts comprise a single, equally related and distinct sub-cluster (see Appendix 7.9 section G) on the dendrogram of the full archaeological and geologic sets (Figure 7.17). All are dolomitic in origin (as indicated by the initial CDA – Figure 7.14), are black or dark grey in color and the majority (7 of 10) were found together in the MR4 area atelier that dates to the site's early Chalcolithic Period (Mehrgarh IIB) (Jarrige 1981: 99). Although in the dolomitic parent-rock CDA (Figure 7.16 B) all were assigned to one of the northern Rajasthan deposits (ANB, ATM or JJK), the actual location of the source is probably not in that region 800 to 900 km to the east-southeast of Mehrgarh. Instead, it is likely somewhere closer to the site in Balochistan or Afghanistan. The Muslimbagh and Las Bela ophiolites can be ruled out as potential sources as the artifacts are composed of dolomitic steatite. In all likelihood, the Neolithic and early Chalcolithic craftspeople at Mehrgarh who used this stone acquired it from an occurrence in central Balochistan such as the one reported (Tariq et al. 1998: 16) in Shirinab Formation shales at Chuttok in the Kalat District, which is just 90 km west of the site. This can only be confirmed, however, after samples from that and related occurrences in the region are collected, analyzed and compared to the Mehrgarh artifacts.

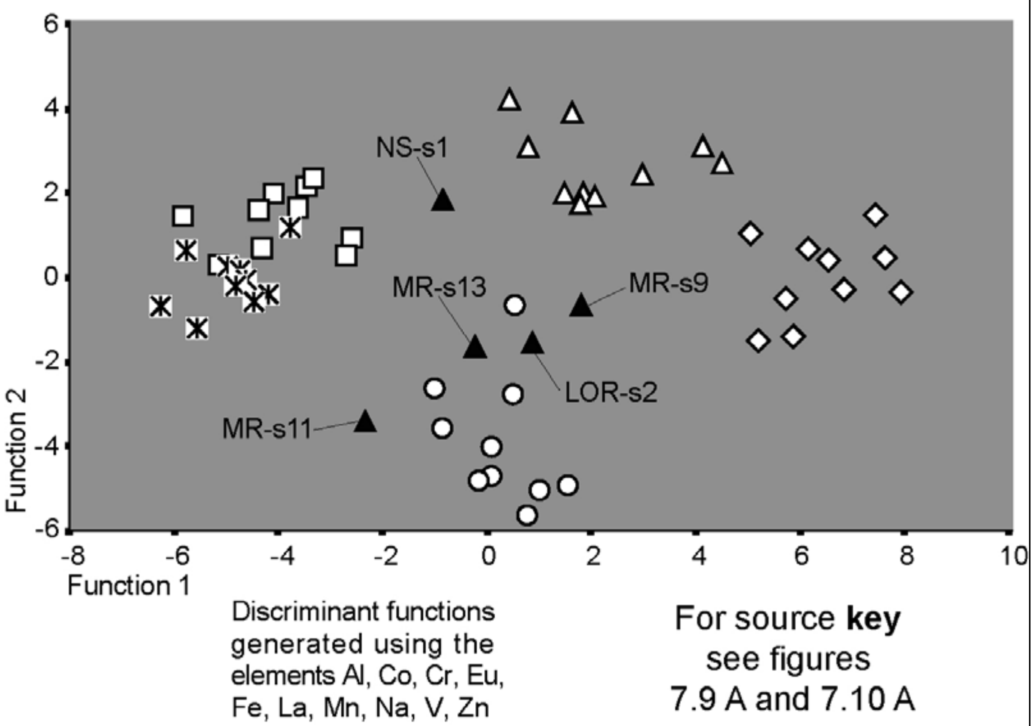
It would appear that the "source" suggested by the ten Mehrgarh artifacts, wherever it is actually located, was used for at least two millennia. Three of the ten artifacts (MR-s8, MR-s10 and MR-s12) were recovered from the site's Period I levels (ca. 7000 to 5500 BC) and the remaining seven (MR-s1 through MR-s7) date to Period IIB (ca. 5000 BC).

Artifacts from the site's later periods will eventually need to be analyzed in order determine if the "source" continued to be used after that. As it now stands, there is no evidence that it was. The single bead from nearby Nausharo, which I discuss shortly, is ultramafic in origin and so cannot be from the same "source." Although many of the 15 dolomitic steatite artifacts from Mohenjo-daro have the same PGMs as the ten from Mehrgarh, on the CA dendrograms (appendices 7.9 and 7.11) they are clearly very different from them compositionally. The artifacts from Harappa with those PGMs likewise appear very different on the dendrograms. On Figure 7.27, I highlighted a sub-cluster of Harappan artifacts that joins the Mehrgarh sub-cluster at RDCC 6. Those artifacts were assigned to the Sherwan zone and I drew attention to them in order show how they may actually be from a different source, *perhaps* in Balochistan, due to their comparatively (in relation to other artifacts from Harappa) close association with the Mehrgarh sub-cluster. I do not, however, believe that they are from the same "source" as the ten Mehrgarh artifacts.

Experimental studies conducted by Barthélémy de Saizieu and Bouquillon (1997: 64) and by myself (Appendix 7.12) have shown that black steatite from Mehrgarh becomes pure white when heated to a sufficient temperature. It is somewhat of a mystery then why the proposed "source" was not exploited by Indus Civilization peoples as this was evidently one of the properties they desired. It might be that the deposit itself was exhausted of good material prior to the Harappan period. Or, perhaps, Indus peoples simply did not have access to the source area, wherever that might have been. Maybe the situation was like that of chert. That is, perhaps one (or just a few) high-quality type of steatite from an extensive source area was used to the almost total exclusion of raw material from minor sources.

The three remaining artifacts from Mehrgarh are each beads or bead fragments from the site's Period I levels. In the first CDA (Figure 7.14), both MR-s9 (composed of a red steatite) and MR-s13 (made from a black steatite) were assigned to ultramafic deposits – DMB and LBW1 respectively. In the second, ultramafic parent-rock only CDA (Figure 7.16 A) their first PGMs respectively shifted to RSB and ZTT. In short, MR-s9 appears more closely related to samples from ultramafic deposits in the southern Rajasthan/Gujarat region while MR-s13 is much more like steatite from the ophiolites of Balochistan. However, with regard to MR-s9, I argue (below) that it is probably actually from a source in a region to the west of the Indus Valley. When it and MR-s13 are compared to a geologic set made up of only the Balochistan sources (Figure 7.28), they are both assigned to deposits in the Muslimbagh ophiolite (MR-s9 to ZTT and MR-s13 to ZTAK).

Figure 7.28: Steatite artifacts from Mehrgarh, Nausharo and Loralai compared to ultramafic steatite sources in Balochistan



Artifact MR-s11 (made from a pale green steatite) is somewhat unusual. Although in the initial CDA it was assigned, like the first ten Mehrgarh artifacts, to a dolomitic northern Rajasthan deposit (JJG), its higher than normal concentrations of certain metallic elements sets it apart from those and all other dolomitic artifacts in the archaeological set. Note its distinct positions on the scatterplots (figures 7.14 and 7.16 B) and dendrograms (appendices 7.9 and 7.11). Although it was not assigned a first (or second) PGM in one of the Muslimbagh ophiolite sources, on the initial CDA scatterplot (Figure 7.14) it falls among the Urgasai Nasir deposit (ZUN) samples, which was one of the ultramafic sources that overlapped the dolomitic ones. Recall that I speculated that this overlap might reflect the deposit's possible formation in a contact zone between magnesium-rich sedimentary rock and the ultramafic rock of the ophiolite. This may have resulted in dolomitic-like steatite bodies with higher than normal concentrations of metallic elements (or vice-versa). Artifact MR-s11, although perhaps not from ZUN, may be from this type of an occurrence. When it is compared to the geologic set made up of only the Balochistan sources (Figure 7.28), it is assigned to the Takhahen (ZTAK) deposit in the Muslimbagh ophiolite.

The broken red steatite bead (NS-s1) from Period III (ca. Period 3B at Harappa) levels at Nausharo clearly appears to be from a source in southern Balochistan. In both the initial (Figure 7.14) and ultramafic parent-rock CDA (Figure 7.16 A), it was assigned first and second PGMs in one of the Wayaro area deposits (LBW1 or LBW2). It was likewise assigned to that region (LBW2) in the CDA using the refined set of samples from the five Balochistan sources only (Figure 7.28). However, on that scatterplot it falls somewhat away from the Wayaro datapoints suggesting that, although it still most closely resembles

steatite from this source, it may not have been obtained from one of those exact deposits. This is not surprising as the geologic samples it is being compared to were collected from modern steatite mines. The raw material for the bead likely came from one of the many old workings and exhausted shear zones (noted above) in the Wayaro area.

The Nausharo bead is one of the very few Harappan period artifacts analyzed in this chapter that is composed of steatite from an ultramafic source. The only others are the fragment (H97-7784-27) from Period 3A at Harappa and two artifacts from Harappan sites in Gujarat (which I discuss shortly). The Nausharo bead and the Harappa fragment are the only ones from the Wayaro source. The bead's Nausharo III / Harappa 3B date means that the raw material could have been acquired via interaction with Indus Civilization peoples who at that time still occupied the settlement of Bakkar Buthi (Franke-Vogt et al. 2000: 199), which is less than 20 km from the source. Later, I argue that Wayaro steatite, although apparently accessible, was not widely used during the Harappan period because it does not fire to a white color. The thick-walled style of the Nausharo bead (Figure 7.7 B bottom row, far right) suggests that it might not have been intended for heat-treatment.

In the end, it is possible to state with a good degree of confidence that one of the beads (MR-s13) from Period 1 at Mehrgarh is made of steatite from a source in the Muslimbagh ophiolite of northern Balochistan, while the bead from Period III at Nausharo is composed of steatite obtained from a deposit in the Las Bela ophiolite of southern Balochistan. The remaining Mehrgarh artifacts (MR-s9, MR-s11 and the ten representing the unknown "source") *could* genuinely be from the deposits in Rajasthan or Gujarat that they were assigned to in the initial CDAs. However, given what is currently understood of

the early cultural sequence at Mehrgarh (Jarrige et al. 2005), I would argue it is far more probable that their actual sources are located to the west of the Indus Valley rather than to the east of it. The recovery of lapis lazuli and marine shell beads in periods I and II levels (Barthélémy de Saizieu 2003: tables 9 and 12) indicates that the interaction networks site residents then participated in stretched northward to Afghanistan and southward to the Arabian Sea. Some of the unsampled sources across that broad area (I have already noted possibilities in eastern Afghanistan) may compositionally resemble those of the Aravalli Range and, thus, steatite from them could have been misassigned to sources in Rajasthan and northern Gujarat. The ten fragments representing the black steatite "source," in all likelihood come from known but unsampled dolomitic occurrences in central Balochistan. Beads MR-s9 and MR-s11 *may* both be from a deposit in the Muslimbaugh ophiolite. If not, then they are still most likely from a source located in Balochistan or Afghanistan.

"Unknown" Loralai site

Although without secure proveniences, the analysis of the sawn fragment and black beads (Figure 7.7 C and D) attributed to an "unknown" site in the Loralai district have provided an informative glimpse of prehistoric steatite usage in northern Balochistan.

In both the initial (Figure 7.14) and dolomitic parent-rock CDAs (Figure 7.16 B), the sawn red steatite fragment (LOR-s1) was assigned first and second PGMs in one of the Sherwan deposits (SC or SKK). However, although clearly of dolomitic origin, the fragment is compositionally quite different from most of the other dolomitic artifacts in the archaeological set, the majority of which were assigned to the Sherwan zone. Note its position apart from the main body of steatite artifacts on Figure 7.16 B (it is identified on

the figure using a red "+") as well as on the dendrogram of the 177 archeological samples (Figure 7.27 and Appendix 7.11). Rather than being from the Sherwan zone, it is more likely that the artifact is either from an unreported dolomitic source in northern Balochistan or, perhaps, one of the unsampled potential sources I noted (above) in eastern Afghanistan.

The black beads are composed of an ultramafic steatite that quite clearly appears to be from a source in the Muslimbagh ophiolite of the northern Zhob District, which is approximately 100 km to the northwest of the Loralai Valley. In both the initial (Figure 7.14) and ultramafic parent-rock CDAs (Figure 7.16 A), the bead analyzed was assigned a first PGM in the Tor Tangi deposit (ZTT). It was assigned to the Takhahen deposit (ZTAK) when compared to the five sampled sources in Balochistan alone (Figure 7.28).

Unlike the ten black steatite artifacts from Mehrgarh that are from the unidentified dolomitic "source," steatite from the ultramafic Muslimbagh ophiolite will not become white when heated (unless it is already white to begin with – and then it turns a dull white). I have confirmed this through heating experiments involving geologic samples from that source formation (Appendix 7.16) as well as one involving the black beads from the "unknown" Loralai site. In the latter, I heated a single bead in a muffle furnace for one hour at 1200ºC. That time and temperature is more than sufficient to turn any steatite white *if it is predisposed to do so* (see appendices 7.12 and 7.16). The bead became a dull reddish-gray color when heat-treated in this way. That, however, was likely not an issue for the craftspeople who fashioned the Loralai beads from Muslimbagh steatite as they probably intended them to remain black. Harappan craftspeople, on the other hand, would not have desired raw material with this property. This is very likely one of the main

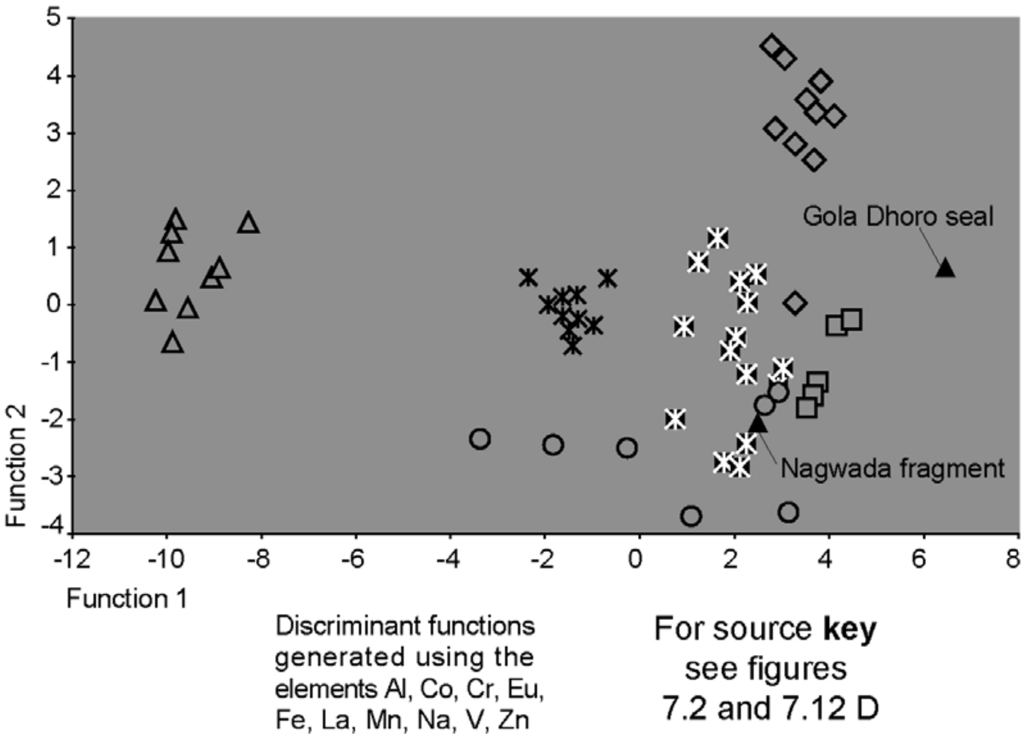
reasons why steatite from the Muslimbagh deposits, despite being in the same general region as a very large Indus Civilization settlement like Dabar Kot, has not been identified among the Harappan period artifacts examined in this chapter.

Nagwada and Gola Dhoro

The INAA results for the fragment from Nagwada and the broken unicorn seal from Gola Dhoro (figures 7.7 E & F) indicate that the Harappans of Gujarat were involved in steatite acquisition networks that were very different from those of their contemporaries at Harappa and Mohenjo-daro. On the scatterplot from the CDA of the full archaeological and geologic sets (Figure 7.14), both artifacts fall squarely among the large cluster of geologic samples from ultramafic sources. This alone sets them apart from 99% of the steatite artifacts analyzed from Harappa and all of those analyzed from Mohenjo-daro.

The Nagwada fragment (NGW-s1) is most closely related to steatite occurring in ultramafic deposits located in the northern Gujarat / southern Rajasthan region. In both the initial (Figure 7.14) and ultramafic parent-rock CDAs (Figure 7.16 A), the fragment was assigned a first PGM in the Shiv Bola (RSB) mine of the Udaipur District, Rajasthan and a second PGM in the Dev Mori-Kundol occurrence (DMK) in the Sarbarkantha District, Gujarat. Both deposits are part of the Rakhabdev Ultramafic Suite of the southern Aravalli Range and when the fragment is compared to samples just from the occurrences in that formation (Figure 7.29) it is assigned a first PGM of DMK. That occurrence is the closest source to the Nagwada. Harappans living at that site might have acquired the steatite by making the 175 km journey east across the North Gujarat Plain themselves or, perhaps, through interaction with the hunter-gatherer populations of that region (Possehl 1980: 73).

Figure 7.29: Steatite artifacts from Nagwada and Gola Dhoro compared to ultramafic steatite sources in southern Rajasthan and northern Gujarat.



The precise source of the steatite used to carve the unicorn seal from Gola Dhoro is somewhat more difficult to pin down. In the initial CDA of the full archaeological and geologic sets (Figure 7.14) it was assigned a first PGM in the Sakhakot-Qila ophiolite deposit (KOT) of the Mohmand Agency. In the CDA involving just ultramafic deposits (Figure 7.16 A), it was again assigned a first PGM of KOT and it was given a second PGM of CHT, which is the source code for samples collected from the Drosh ophiolite near Tar village in the Chitral District. In spite of these consistent assignments to the ultramafic deposits in the ophiolites of northern Pakistan, I consider it most unlikely that the steatite used to carve the seal was actually derived from that region. My doubts on this matter do not stem from the great distance that exists between Gola Dhoro and the KOT and CHT deposits (around 1250 and 1400 km respectively). Beads made of lapis lazuli – a stone that

originates even farther away (≈ 1475 km) in northern Afghanistan, have been recovered at the site (IAR 1996-97: 25). Rather, I base my reservations on what we are now beginning to understand of steatite use and acquisition at Indus Civilization settlements located between northern Pakistan and the Gujarat region. The seal could have been manufactured at a settlement that was comparatively closer to the KOT and CHT deposits, such as Harappa or Mohenjo-daro, and then discarded by a trader or some other person visiting or returning to Gola Dhoro. However, the results of this study suggest that it is not likely to have been made at either of those cities as craftspeople at them seldom (if ever) used any ultramafic steatite, much less any from those particular sources in northern Pakistan. The seal could have also been made at a Harappan settlement in Gujarat using raw material obtained from the distant KOT or CHT deposits. But if this was the case then the evidence would indicate that the acquisition/trade networks for that kind of steatite, which presumably would have gone through the Indus Valley, bypassed the major Indus urban centers. I consider that to be an unlikely possibility. Admittedly, however, the low sample sizes from those cities (particularly Mohenjo-daro) means that examples of ultramafic steatite artifacts from northern Pakistan sources may have simply missed being detected.

In all likelihood the Gola Dhoro seal was manufactured in Gujarat using ultramafic steatite from a deposit located somewhere other than northern Pakistan. The artifact's compositional similarity to samples from the Sakhakot-Qila and Drosh ophiolites suggests that the actual raw material source *might* be found in the same type of geologic formation. The Las Bela ophiolite of southern Balochistan is the nearest such formation but, as I have already noted several times and will discuss further in the next section, steatite from

deposits occurring in it evidently does not become white when heated. Thus, the white Gola Dhoro seal is probably not composed of raw material derived from that formation. The Semail ophiolite of Oman (not shown on Figure 7.2), although located 1200 km to the west across the Arabian Sea, should be considered a potential source because of the clear evidence for the existence of maritime interaction networks between Eastern Arabia and the Gujarat region during the Harappan Period (Chakrabarti 1998; Edens 1993; Possehl 1997a; Rao 1979b). However, until samples from deposits in that formation are collected and analyzed, it is impossible to do more than speculate as to whether or not steatite was among the raw materials that may have been exchanged through those networks.

In the end, it is most probable that steatite used to make the Gola Dhoro seal came from one of the ultramafic deposits nearest to the site itself. In the initial CDA of the full archaeological and geologic sets (Figure 7.14), the second PGM of the seal was the Dev Mori-Kundol occurrence (DMK) in the Sarbarkantha District of northern Gujarat. If the KOT and CHT deposits are removed from the full geologic dataset and another CDA is performed (not shown) then DMK becomes the artifact's first PGM. When the seal is compared to just the sampled ultramafic deposits of southern Rajasthan and northern Gujarat (Figure 7.29), it is assigned a first PGM in the Rishab-der deposit (RRD) of the Udaipur District and a second PGM of DMK. Note that on the scatterplot for that CDA the artifact plots away from the clusters representing those deposits. This suggests that it is perhaps not from either one of those exact sources, which not surprising as they are modern mines. It could still very well be from a related deposit in the same geologic formation, however. There are a half-dozen reported occurrences around the Dev Mori area

(Chatteerjee 1964: 436) in addition to the two sampled for this study (DMK and DMB). Moreover, scores of other sources might have been accessible to Harappans (or their suppliers) elsewhere in the Rakhabdev Ultramafic Suite, which continues northward from Gujarat into steatite-rich southern Rajasthan (Gupta et al. 1997). It is hoped that an expanded program of sampling across that formation will one day permit a more geographically accurate identification of the source of the steatite used to make the seal.

Tepe Hissar

When the four pieces of sawn steatite from the site of Tepe Hissar (Figure 7.7 G) in northern Iran are compared to all 37 deposits in the geologic dataset (Figure 7.14), each is predicted to belong to a dolomitic source located in Rajasthan (TH-S1 and TH-S3 = RSA, TH-S2 and TH-S5 = ATM). The results were the same when the fragments were compared to samples from just the 23 dolomitic deposits in the dataset (Figure 7.16 B). On the CA dendrogram of the 177 archeological samples (Figure 7.27), one of the fragments (TH-s2) groups apart in a small distinct cluster to the right of the RDCC 25 split but the rest are very similar compositionally to artifacts from Harappa and Mohenjo-daro. Had the four fragments been recovered at one of those sites instead of in Iran then there would be little reason to argue that they were derived from a source area other than the one that they were predicted belong to by CDA. However, because of the artifacts' archaeological provenience their PGM assignments must be regarded cautiously.

It is not impossible that the four Tepe Hissar fragments are genuinely composed of steatite that was extracted from deposits in Rajasthan and then transported over 2200 km to consumers in northern Iran. Raw materials and/or finished items were sometimes moved

tremendous distances across late Bronze Age southern and western Asia (Ratnagar 2004). This fact is best exemplified by the distribution of lapis lazuli artifacts at sites from Egypt to the Indian Subcontinent (Casanova 1997; Herrmann 1968; Tosi 1974; von Rosen 1990). The unmistakably Harappan-style "etched" (bleached) carnelian beads recovered in Tepe Hissar IIIC levels (ca. late 3rd / early 2nd millennium BC) and at several other late Bronze Age sites in Iran (Heskel 1984: 341) demonstrate that some material goods made it to that distant region from South Asia during the Harappan Period. However, there was only one viable source of lapis lazuli in this part of the ancient world (see Appendix 4.4) and the Harappans were the only ones who were creating "etched" carnelian beads at that time. There were no other sources available to consumers in ancient Iran (or elsewhere) who wished to posses such items. Steatite, in comparison, would have been widely available. Although I will shortly argue that raw material from certain deposits was, depending on what was being manufactured, preferred over that from other deposits, there is no reason at this point to believe that those preferable types only occurred in South Asia. If we presume that the Tepe Hissar steatite was from a source closer to that site in Iran or Afghanistan then it would indicate that there are dolomitic deposits in those regions to the west of the Indus Valley that are compositionally similar the ones in Rajasthan. This possibility allows the PGMs of some of the artifacts analyzed from other sites to be considered in a new light.

I previously argued that artifacts from Mehrgarh assigned to steatite deposits in Rajasthan were very likely to have been, in actuality, derived from a source or source area located to the west of the Indus Valley in central Balochistan or, perhaps, in Afghanistan. Although the Tepe Hissar fragments do not appear to be from the same source(s) as those

particular artifacts (observe their dissimilarly on the CA dendrogram of Figure 7.27), they do, as already noted, closely resemble some of the ones from Harappa and Mohenjo-daro. Respectively, around 5% and 40% of the artifacts analyzed from those two cities were predicted to belong to steatite deposits in Rajasthan. One may ask – If the PGMs assigned to the Tepe Hissar fragments are questionable, then might those artifacts from Harappa and Mohenjo-daro that are likewise predicted to belong to sources in Rajasthan potentially be misclassified? And if so, then is it possible that the steatite such artifacts are composed of instead came from the same source or source area as the compositionally similar Tepe Hissar fragments? The answer to both questions is – most definitely yes, it is very *possible*.

The evidence provided by the Tepe Hissar artifacts, although indirect and limited, suggests that occurrences of dolomitic steatite that are compositionally analogous to those in Rajasthan may exist in regions to the west of the Indus Valley. This means that artifacts from Harappa and Mohenjo-daro that were assigned PGMs in Rajasthan deposits could *possibly* instead be from occurrences in Afghanistan or, perhaps, even Iran. However, this possibility cannot be tested until samples from dolomitic sources in the latter two regions are obtained, analyzed and compared to the artifacts from those sites. Therefore, for now, the northern Rajasthan provenience assignments made for certain artifacts from Harappa and Mohenjo-daro will stand and be used to designate a regional point of origin in the upcoming summary of Indus tradition steatite acquisition networks (Figure 7.30). Nevertheless, it should be recognized that although all provenience determinations made in this chapter are provisional, the PGMs for those artifacts are perhaps the most liable to change when samples western regions are eventually incorporated into the geologic dataset.

Summary and discussion

Steatite occurs in every major highland region surrounding the Indus Basin. Yet the provenience composition of the raw steatite assemblage at Harappa is far less variable, both synchronically and diachronically, than might be expected given the evidently high demand for this variety of rock and the geographical wide distribution of potential sources. For the better part of two millennia, residents of Harappa acquired most of the raw material they used from only a handful dolomitic sources located in the northern part of present-day Pakistan and India. In this final section, I first review the various steatite acquisition networks that were identified in this chapter. I then discuss the heat-treatment of steatite by Indus Tradition peoples and their need for raw material that would become white when it was fired. I argue that this need is probably the main reason behind the sustained use by Harappans of one type of steatite from a single, albeit broad, source region.

Figure 7.30 depicts the Indus Tradition steatite acquisition networks provisionally defined in this chapter. Each are indicated using a line with an arrow on its terminal end. Green lines are networks for dolomitic steatite and black lines are networks for ultramafic steatite. The routes from the sources to the sites are entirely conjectural. Variations in line thickness for networks to Harappa, Mohenjo-daro and Mehrgarh are meant to approximate the overall assemblage provenience compositions for those sites. For example, the network from the "northern" region to Mohenjo-daro is drawn with a line 6-points in width as 60% of the artifacts analyzed were assigned to sources there. A 4-point line was used to represent the 40% of artifacts from that site assigned to northern Rajasthan sources. Dashed lines (with a "?") indicate networks for which the steatite source is conjectural.


Figure 7.30: Indus Tradition steatite acquisition networks (provisional).
Dolomitic steatite
Ultramafic steatite
source location conjectural
NORTHERN AREAS
AFGHANISTAN
Hazara (Sherwan) deposits
Prang Dera
Peshawar Valley
KURRAM
KHYBER
Daradar
N W F P
KASHMIR
Painthal
"northern" region
JAMMU
Bannu Basin
Gomal Plain
Jhelum River
Chenab River
HIMALAYAS
HIMACHAL PRADESH
Ravi River
Beas River
Muslimbagh deposits
ZHOB
THAL DESERT
Harappa
LORALAI
Sutlej River
BALOCHISTAN
PUNJAB
UTTARANCHAL
KALAT
Mehrgarh
Nausharo
Bolan River
Hakra River
Ghaggar River
HARYANA
INDUS RIVER
Gangetic Plain
Ganga River
Yamuna River
Las Bela deposits
Mohenjo-daro
Jhunjhunu deposits
Alwar deposits
RAJASTHAN
ARAVALLI RANGE
SINDH
Balakot
Udaipur & Dungarpur ultramafic deposits
Nagwada
Dev Mori
KUTCH
ARABIAN SEA
Gola Dhoro
GUJARAT
Mahi River
SAURASHTRA
N
0 km
200

Temporal change was not illustrated on Figure 7.30 because to do so would have required either multiple maps or a single one with many more lines/arrows and labels (this was attempted but was too busy visually). A phase-by-phase review of the steatite acquisition networks for Harappa is presented as part of the Chapter 13 summary of all geologic provenience studies conducted in this dissertation. Despite the lack of time depth, the figure does effectively depict the general acquisition patterns that are now evident for each site and for the Greater Indus region as a whole. With the final caveat – some or all of the networks defined here may change dramatically when additional steatite sources are incorporated into the geologic dataset; the following summary of the results is presented.

Indus Tradition steatite acquisition networks (provisional)

The Harappans' Indus Tradition predecessors at Mehrgarh acquired black dolomitic steatite from a source that was probably located relatively close by that site in central Balochistan. They also used some ultramafic steatite from the Muslimbagh ophiolite of northern Balochistan. Prehistoric peoples dwelling somewhat farther to the north in the Loralai Valley likewise acquired raw material from the Muslimbagh ophiolite, as well as red dolomitic steatite that was either from some unreported local occurrence in northern Balochistan or, perhaps, one of the known dolomitic deposits of Afghanistan. Later craftspeople at Harappa and the other Indus Civilization sites examined do not appear to have utilized steatite from any of the same sources as the ancient peoples of Mehrgarh or the Loralai Valley. However, the fragments analyzed from Tepe Hissar in Iran suggest that there were other dolomitic occurrences in the regions to the west of the Indus Valley from which some of the artifacts from Harappa and Mohenjo-daro could have *possibly* originated.

The earliest residents of Harappa (Ravi Phase / Period 1) used dolomitic steatite acquired through networks that extended 330 km northeast to Jammu and, perhaps, 500 km southeast to northern Rajasthan. By the Kot Diji Phase (Period 2) the largest percentage of raw material brought to the site was derived from dolomitic deposits located 400 km north in the Sherwan area of the NWFP. The Sherwan deposits remained the primary source of steatite for craftspeople at Harappa throughout the urban phase (Period 3) and into the Late Harappa Phase (Period 5). During that time, raw material continued to be brought from Jammu (through Period 3B) as well as other dolomitic sources in the “northern” region like Prang Dera in the Khyber Agency (through Period 5) and Daradar in the Kurram Agency (intermittently through Period 3C). Only very minor amounts of steatite were acquired from sources other than those to the north of Harappa. At least some raw material of ultramafic origin was obtained during Period 3A as indicated by a single fragment from the Wayaro source in the Las Bela ophiolite of southern Balochistan. A few examples of dolomitic steatite from periods 3B and 3C suggest that residents of Harappa had some degree of access to sources in northern Rajasthan at that time. Overall, however, Harappa’s unfired steatite artifact assemblage is, in all periods and parts of the site, dominated by raw material acquired from “northern” region occurrences, in particular stone from the Sherwan area deposits (thus on Figure 7.30 the thickest network line is drawn from it to Harappa).

When provenience data from the other Indus Civilization cities and towns examined in this chapter are combined with that from Harappa, a more complex picture of steatite acquisition in the Greater Indus region during the Harappan Period begins to emerge. We see that the residents of Nausharo in central Balochistan had access to the ultramafic

deposits of the Wayaro area, which is around 380 km to the south in the Las Bela region. Interestingly and significantly, however, there is at present no evidence that raw material from those deposits was brought to Mohenjo-daro, despite them being the absolute closest sources to that city (≈ 200 km to its southwest). The single ultramafic fragment from Period 3A at Harappa, which was derived from a Wayaro area deposit, might therefore have been transported to that site along a network that passed through central Balochistan rather than Sindh (on Figure 7.30 I have drawn the conjectural route for that network through Nausharo). Craftspeople working at Mohenjo-daro used dolomitic steatite; the majority of which came from the same sources in the "northern" region used by residents of Harappa (on Figure 7.30 the "northern" region network to Mohenjo-daro is conjecturally routed through Harappa). A smaller but significant portion of the raw material at Mohenjo-daro appears to have been acquired from the northern Rajasthan region. To the south, the Indus Civilization peoples of Gujarat were doing things very differently than their fellow Harappans in Sindh and the Punjab. Both the fragment from Nagwada and the Gola Dhoro unicorn seal are composed of ultramafic steatite – a kind identified only once at Harappa and never at Mohenjo-daro. Harappans at Nagwada acquired that raw material from the source nearest to them in southern Aravalli Range and it is quite probable that the Gola Dhoro seal was carved from stone derived from a deposit in that region as well.

These are the steatite acquisition networks of the ancient Greater Indus region as they are currently understood. There is every reason to expect that at least some of them might change when the comparative dataset of geologic sources is enlarged. Likewise, the regional picture of the networks is almost certain to become considerably more complex as

artifacts from additional sites are analyzed. Nevertheless, even at this initial stage and in spite of the provisional nature of the provenience determinations, several significant new insights into the acquisition and use of steatite by Indus Tradition peoples have been gained. To begin with, we have learned that, despite the wide distribution of potential sources around the Greater Indus region, craftspeople at Harappa, regardless of the chronological phase or part of the site in which they lived, mainly used steatite derived from a limited number of deposits located in the northern parts of Pakistan and India. Residents of Mohenjo-daro evidently either disregarded or did not have access to steatite deposits relatively close by in Balochistan and instead imported raw material from the same, much more distant sources used by their contemporaries at Harappa. The Harappans of Gujarat seem to have been involved in separate, regional acquisition networks that extended to the nearest steatite deposits of the southern Aravalli Range. Lastly, it is beginning to appear that Indus Tradition craftspeople, from the Neolithic Period at Mehrgarh through the Late Harappan Period at Harappa, were, with some important exceptions, either mainly or exclusively using steatite of dolomitic origin.

The last insight is especially significant as it may help to explain, at least in part, why certain steatite sources, some of which were relatively close by Indus Tradition settlements and presumably assessable, were used either rarely or not at all. If stone that would become white when heated was desired (and it evidently was), then, as I discuss next, it appears that only certain dolomitic occurrences could have provided raw material with that property. I argue, therefore, that technological/aesthetic considerations, more than source proximity/accessibility, dictated which steatite sources were used.

Heat-treating steatite and the need for "white-firing" stone

Massimo Vidale noted (1989b: 180) that "in all Harappan craft production, a major emphasis [was] placed on the creation of artificial substances more than on the employment of precious, well recognizable raw materials." Few rocks or minerals would have satisfied the impulse to transform a raw material into something new better than steatite – a stone that undergoes significant physical changes when it is subjected to high temperatures. By heating steatite, Harappans and their Indus Tradition predecessors sought to greatly increase its durability by making it harder and dramatically alter its appearance by turning it white. Studying the mineralogical composition of heated artifacts enables archaeologists to assess and track the ability of Indus craftspeople to transform steatite in this way.

When sufficiently heated (also referred to as "fired" or "burnt"), steatite undergoes a variety of physical transformations. The mineralogical changes that result from the dehydration and thermal decomposition of talc (steatite's primary mineral constituent) are very well-documented (see Bose and Ganguly 1994 for a discussion of dehydration kinetics and Wesolowski 1984 for a review of various heating studies). Typically, talc decomposes to *enstatite* (magnesium silicate) and amorphous silica between around 900ºC and 1000º C. At temperatures above 1100ºC the amorphous silica will begin to crystallize as *cristobalite* (the high-temperature polymorph of quartz). Firing time, atmosphere and the composition of the raw material can all differentially affect the rate and temperature at which these changes take place, however. Experimental studies on steatite, similar to those conducted to replicate the firing conditions of Harappan ceramics manufacture (Kenoyer 1994a), are currently being undertaken by Dr. Mark Kenoyer and Gregg Jamison at University of

Wisconsin-Madison. Experiments also have been conducted by Barthélémy de Saizieu and Bouquillon (1994) and by myself (appendices 7.12 and 7.16) that involved the heating of raw steatite in electric kilns at different temperatures and the analysis of those samples using XRD. These studies (and the others cited above) have provided a framework for using the mineral phases detected in heated steatite artifacts to judge the approximate temperatures to which they were subjected (note that I am referring to objects made from massive steatite and not talc glazes or objects that made from powdered steatite "paste").

As noted near the beginning of this chapter, black steatite beads recovered in the very earliest (ca. 7000 BC) pre-ceramic Neolithic levels (Period I) at Mehrgarh constitute the first evidence for the use of that stone by Indus Tradition peoples. The first indication that Indus craftspeople might have begun to heat-treat steatite comes later in that same period at Mehrgarh (ca. 6200 BC – formerly the beginning of Period IB) in the form of white beads composed of *anthophyllite* and talc (see Barthélémy de Saizieu and Bouquillon 1994: 51 and Appendix 7.13 in this dissertation). Those beads could be made from natural, unheated stone as anthophyllite (magnesium iron silicate hydroxide), like talc, is sometimes white in color (Deer et al. 1992: 232-236). On the other hand, an anthophyllite phase intermediate to talc and enstatite reportedly can develop when talc is heated between 667 and 745ºC (Greenwood 1963). The beads could, therefore, represent the initial modification of steatite using relatively low heat. However, an anthophyllite phase was not replicated in either Barthélémy de Saizieu and Bouquillon's experimental heating study of Mehrgarh steatite (1994) or in my own (Appendix 7.12). For this reason, the heat-treatment of steatite during Period I at Mehrgarh must, at present, be considered unconfirmed.

Steatite was unquestionably being heat-treated by the late Neolithic (Period IIB ca. 5000 to 4500 BC) / early Chalcolithic (Period III – ca. 4500 to 3800 BC) periods at Mehrgarh. Using XRD, I analyzed two white beads recovered from a Period IIB level at that site (Appendix 7.13). Both exhibited minor enstatite peaks among the talc peaks, which suggest that they were probably heated to around 900ºC for about one hour (or perhaps at a slightly lower temperature for a longer period of time). During Mehrgarh Period III, 93% of the beads in the site's assemblage are composed of heat-treated steatite (Barthélémy de Saizieu and Bouquillon 1994: 52). By the third millennium BC (Harappan Period), Indus Tradition craftspeople were firing steatite at temperatures that clearly exceeded 1100ºC (perhaps closer to 1200º C) as evidenced by artifacts analyzed from Harappa and Mohenjo-daro that in XRD scans exhibit very well-developed enstatite and cristobalite phases (Vidale 2000: 63 and Appendix 7.14 in this dissertation).

Depending on its mineral composition, raw steatite can have a Mohs' hardness value of anywhere between around 1 (for types that are almost pure talc) to around 2.5 (*personal observations*). Low hardness combined with the compact, homogenous nature of good quality steatite allowed it to be sawn into thin chips that could be easily perforated and ground into beads (Vidale 1995), as well as shaped into seals (Rissman 1989) and tablets (Meadow and Kenoyer 2000) onto which inscriptions and/or various motifs were carved. However, in its raw form the stone is not very durable (it can easily be scratched with one's fingernail). By heat-treating steatite, Indus craftspeople could raise its hardness considerably. This has been documented Beck (1934: 77-82), Ritchie (1973: 48) Hegde and others (1982) and by myself (Appendix 7.16). The formation of enstatite imparts a

steatite object with a hardness of between 5 and 6 (Deer et al. 1992: 155) and cristobalite of between 6 and 7 (ibid.: 457). Although increased hardness would have made such objects more durable, I would argue that this was not the main reason that they were heat-treated.

With the exception of the Neolithic period at Mehrgarh, when unfired black steatite beads were most abundant (Barthélémy de Saizieu 2003: 24), the vast majority of *finished* steatite artifacts recovered at Indus Tradition sites are white in color and appear to have been heat-treated. Most are fired white completely throughout. Some artifacts, like stamp seals, have a white veneer that is the result of heating and either the application of a talcose glaze (Mackay 1931d: 379) or an alkaline surface treatment (Beck 1934: 80-81; Vidale 2000: 62). I tend to slightly favor the former explanation based on observations that I have made (Appendix 7.15). However, both techniques may have been used, perhaps at times in combination with one another. In any case, it is probably safe to conclude that, in most instances, a white appearance was the desired outcome when Indus Tradition craftspeople subjected objects fashioned from steatite to high temperatures.

Indus craftspeople apparently did not acquire and use raw steatite that was already white to begin with. None has been encountered among the nearly 3000 unfired artifacts and fragments at Harappa and to my knowledge none has been reported from other Indus Tradition sites (except, perhaps, the previously discussed white talc-anthophyllite from Mehrgarh, which may or may not be natural). Although it is possible that every scrap of white raw material was heated (and, thus, none was left to be recovered), such a scenario seems to me unlikely. It could be that this type of steatite, being the most chemically pure and least hard, was too soft and friable to be good carving stone. Or it might be that it was

difficult to obtain since white stone does not tend to be found near the surface or at the easily accessible margins of steatite deposits (*personal observations*). However, it may be that Indus Tradition peoples preferred to use steatite that was colorful because it fulfilled an impulse to transform a raw material into something different. As heat is increased, the transformation of colored steatite to white is "visually impressive … it might have been perceived as a magic process and might have suggested to the ancient craftspeople the idea of progressive purification" (Vidale 2000: 59).

In her doctoral dissertation on Indus Tradition pyrotechnologies, Heather Miller wrote (1999: 306) that "although found in various colors from white to creme to green to black, all varieties [of steatite] become white when fired to high enough temperatures." This would appear to be an unstated assumption of many South Asian archaeologists. However, IT IS SIMPLY NOT TRUE. I have conducted a series of heating and characterization studies (Appendix 7.16) using geologic samples from several dozen of the steatite deposits featured in this dissertation. Although these studies are still ongoing, one thing is already quite clear. That is, there are some types of steatite will become a pure bright white when fired and there are other types of steatite that will never become white regardless of how long or how high they are heated. Those types that do become white (or near white) when they are heat-treated are almost invariably from **dolomitic deposits**. Moreover, of the various dolomitic deposits examined in this chapter, those that exhibit the whitest firing steatite are the very same sources from which the majority of the unfired steatite artifacts at Harappa and Mohenjo-daro were predicted to have been derived. My apologies for the liberal use of emphasis in this paragraph but these are observations that go

to the very core of two important issues raised by the results of the provenience study conducted in this chapter, which are: Why did Indus Tradition peoples mainly use dolomitic steatite and why did Harappans (at least those at Harappa and Mohenjo-daro) mainly acquire it from just a handful of deposits in the “northern” region when there were other, often closer sources? I now briefly look at both of these issues.

First. *Why the emphasis on dolomitic steatite*? In his examination of ancient steatite vessels from Eastern Northern America, James Truncer made a pertinent observation about the use of raw material from ultramafic and dolomitic (which he calls *sedimentary*) deposits:

> No steatite vessel quarries have been documented at outcrops of sedimentary origin, a distinction not previously recognized by archaeologists. The use of ultramafic steatite is consistent with the largely held assumption that steatite vessels functioned as fireproof containers because steatite vessels of sedimentary origin would perform poorly in fire (Truncer 2004: 490).

I would argue that raw material of dolomitic origin was favored by Indus Tradition craftspeople for precisely the same reason that it was disregarded by vessel-makers in Eastern North America – because of the way it behaves when subjected to high temperatures. Indus Tradition consumers needed steatite that would become white when fired and my experimental heating studies (Appendix 7.16) indicate that dolomitic steatite is more apt to do that than ultramafic steatite. I strongly suspect that the reason for this has to do with, at least in part, the different concentrations of metallic elements that are found in the two kinds of steatite, i.e. – very high concentrations in stone of ultramafic origin vs. very low concentrations in dolomitic steatite. In my heating experiments, the ultramafic geologic

sample that was lightest in appearance (although not pure white) after being fired came from the Urgasai Nasir deposit (source code ZUN) of northern Balochistan (see Figure 3 in Appendix 7.16). Recall from the CDA of the full geologic set (Figure 7.13) that this was one of the ultramafic deposits that partially overlapped with the dolomitic ones because some samples from it had untypical low concentrations of certain metallic elements.

So in both parts of the ancient world we see that technological considerations – the need for white-firing steatite in the Greater Indus region and for fire-resistant material in Eastern North America, influenced which kinds of steatite deposits were exploited.

Now on to the second issue – *why did residents of Harappa and Mohenjo-daro acquire the majority of their dolomitic steatite from deposits in the "northern" region*? For consumers at Mohenjo-daro, deposits in northern Pakistan and India definitely were not the closest occurrences of dolomitic steatite. With regard to Harappa, some of the "northern" sources (those in Jammu) did constitute the nearest locations where steatite of that kind could be acquired. However, the others (those in the Sherwan zone and in the FATA) were more or less the same distance from the site as the dolomitic deposits of northern Rajasthan. In fact, those other sources may have been more difficult to reach than the ones in Rajasthan due to the fact that there are many more rivers and mountain ranges that lie between them and Harappa. So why, then, of all the potential dolomitic sources in the Greater Indus region, was steatite from a few deposits in northern Pakistan/India the preferred raw material at those two Harappan cities? After having heat-treating samples from most of the dolomitic deposits examined in this chapter (Appendix 7.16, Figure 8), the answer would seem to be that <u>steatite from "northern" region sources fired the whitest</u>.

Thus, I would argue that the aesthetic requirements of Harappan craftspeople (their desire for white-firing stone), more than source proximity and/or difficulty of access, probably dictated which dolomitic steatite deposits were exploited.

The heating experiments reported in Appendix 7.16 have also provided information that may help to clarify patterns suggested by the cluster analysis of the full geologic and archaeological steatite sets. Recall that on the dendrogram (Figure 7.17 and Appendix 7.9) there are several large groups of the artifacts that exhibit a degree of compositional homogeneity that is more pronounced than even that of geologic samples collected from individual steatite deposits. I suggested that those closely related artifact clusters possibly represent raw material exploited from a very restricted area within an occurrence, such as a single outcrop, vein, pit or mine. Heating experiments indicate that steatite from within the individual deposits of the Sherwan zone – the source that the majority of artifacts from Harappa were predicted to belong to, is itself variable in terms what will become white and what will not. Samples from the Chelethar (SC) and the Khanda Khu (SKK) deposits became white in one heating but failed to do so in another (Appendix 7.16, figures 3 and 8). When sampling those locations, both of which extend over several hundred meters and encompass numerous pits and mine shafts (both old and modern), I was concerned with documenting intra-source variability and so collected a spatially wide range of material from them. However, it is highly likely that prior to transporting just any seemingly good-quality stone over 400 km to Harappa, whoever was extracting steatite from those (or any other) deposits during the prehistoric period would have located the specific, perhaps very restricted places within them where the whitest-firing material occurred. The intensive and

sustained exploitation of raw material from such intra-source locations *could* account for the clusters of highly compositionally similar artifacts evident on the CA dendrogram.

Before concluding it is important to again acknowledge that eight of the 177 steatite artifacts analyzed in this chapter were determined not to be composed of dolomitic steatite. Although many of those were finished beads or other objects like the BMAC wig that were never meant to fired, one of them – the Gola Dhoro seal (Figure 7.7 F), clearly has been. That artifact does not have a bright white exterior like most Harappan steatite seals and beads, but it is much lighter in appearance than any of the samples from ultramafic deposits that I heat-treated in Appendix 7.16 (save for the previously mentioned ZUN sample, which [1] was white to begin with and [2] had low concentrations of metallic elements). There are a small number of finished, heat-treated steatite seals from Mohenjo-daro that exhibit a muddy red-colored exterior (for examples see Shah and Parpola 1991: color plates 7, 15 and 17) that resembles the post-firing appearance of many of the geologic samples I tested (Appendix 7.16, Figure 3B). Such seals were probably carved from and/or glazed with steatite that was not predisposed to fire to the white color that was desired by their manufacturers. The very light-gray color of the Gola Dhoro seal indicates that its makers had either succeeded in identifying/acquiring a type of ultramafic steatite that would fire near white *or* had the ability to lighten the exterior of non-white firing stone, perhaps by employing the same technique used to bleach white designs onto carnelian beads (Mackay 1933). I attempted to whiten that kind of steatite using different alkali solutions (detailed in Appendix 7.16) but was unable to affect any change in the stone's appearance. Although my failure does not prove that Indus Tradition craftspeople were incapable of bleaching

stone of ultramafic origin, it does appear as if those working at Harappa (and probably Mohenjo-daro too) either could not or chose not to whiten this kind of steatite. Had they done so on any significant scale then odds are that more than one example of ultramafic stone would have been identified among the 139 fragments and unfired artifacts (≈ 5% sample of the sub-assemblage) that were analyzed from the site. The real point, however, is that they did not have to. The results of the provenience study indicate that people at those cities acquired the majority of their steatite from "northern" region sources that, as shown by the heating studies, contained raw material that was predisposed to fire white.

What then of the Gola Dhoro ultramafic steatite seal? Perhaps it indicates that the makers of that object did not have access to white-firing stone from the "northern" region and, like the Harappans of Nagwada, had to make due with the nearest available steatite, which was ultramafic in origin. This may have prompted them to invent or adapt whitening technologies that their fellow Harappans in the Indus Valley either did not possess or, more likely, did not need to use on steatite (because they had access to white-firing stone).

Chapter conclusion

From the Ravi through the Late Harappa phases, residents of Harappa acquired almost all of the raw steatite they used from dolomitic sources located in the northern part of present-day Pakistan and India. Craftspeople in different parts of the site seem to have had access to raw material from that same broad source area. "Northern" dolomitic steatite was transported as far south as Mohenjo-daro but apparently was not used in Gujarat. In the next chapter, I examine agate – a broad variety of stone that appears to have been transported from several sources in Gujarat to Harappa and other sites in the Indus Valley.

Chapter 8

Agate acquisition networks

Chapter 8 – Agate acquisition networks

Chapter introduction – Sourcing Harappan agate

The roughly 4700 finished objects (mostly ornaments but also the occasional stone weight) and pieces of raw material or manufacturing debris from Harappa that have been designated *agate* or *jasper* (see pp. 131-132) exhibit a bewildering range of macroscopic variability (recall Figure 4.3 C for just a handful of examples). Although HARP co-director Dr. J. Mark Kenoyer has developed an intricate coding system for describing such variation, visual attributes alone cannot be used to identify their geologic sources. As was the case for steatite, multiple macroscopic types of agate and jasper are usually found at source locations (*personal observations*) and, in fact, often are present in individual specimens (note, for instance, the variegated appearance of some of the agate samples pictured in Figure 8.10 D). Moreover (and also like for steatite), Indus craftspeople likely altered the original appearance of certain sub-varieties of these microcrystalline silicates when they heat-treated them (described in Kenoyer et al. 1991). The secondary contexts from which agates and jaspers are frequently obtained, like riverbeds and conglomerates, may contain materials that formed across extremely wide areas and in very different geologic episodes and/or environments. Recent attempts to provenience of *carnelian* (red-orange agate) artifacts using PIXE analysis (Theunissen et al. 2000) and LA-ICP-MS (Insoll et al. 2004) have produced largely equivocal results. It was for all of the above reasons that I initially approached the sourcing of this material sub-assemblage with low expectations of success.

In order to make this aspect of my research more manageable, I narrowed the focus to just agate and a very specific research question. I decided to evaluate the long and

widely held "assumption" (Ratnagar 2004: 146) that Harappans derived their agate primarily from sources in Gujarat; most probably the deposits of the Ratanpur area in the southern part of that Indian state (Allchin and Allchin 1997: 173; Asthana 1993: 274; Biwas 1996: 49; Lal 1997: 163-164; Pascoe 1931: 681; Vidale 2000: 42). Using INAA, agate samples collected from Ratanpur and two other sources located in northern Gujarat were analyzed. These were then compared, using CDA, to one another and to agate artifacts from the prehistoric site of Shahr-i-Sokhta in eastern Iran, which were treated as proxy samples for sources in that distant region. Good to excellent (≈ 85 to 95%) statistical separation between grouped samples from these sources/proxy sources was achieved. When agate artifacts from Harappa and five other Indus Tradition sites were compared to them, it was found that although most are analogous to geologic samples from the Gujarati deposits, very few appear to be from the Ratanpur source. The results also indicate that Harappans may have been acquiring some agate from sources in regions other than Gujarat.

In this chapter, I recount what, despite my initial expectations, has turned out to be a successful provenience study of Harappan agate. It is presented in two main parts. In the first, I discuss the formation of agate and agate deposits and then outline potential sources of that stone in the Greater Indus region and beyond. I begin the second part by presenting the geologic dataset and the agate artifacts (from Harappa and five other sites) that are compared to it. Multiple discriminant analyses involving different combinations of source samples are then carried out and provenience determinations are assigned. Afterwards, the results are scrutinized and, when necessary, qualified. In the final section, I discuss their implications for future research of this kind and summarize the provisional conclusions.

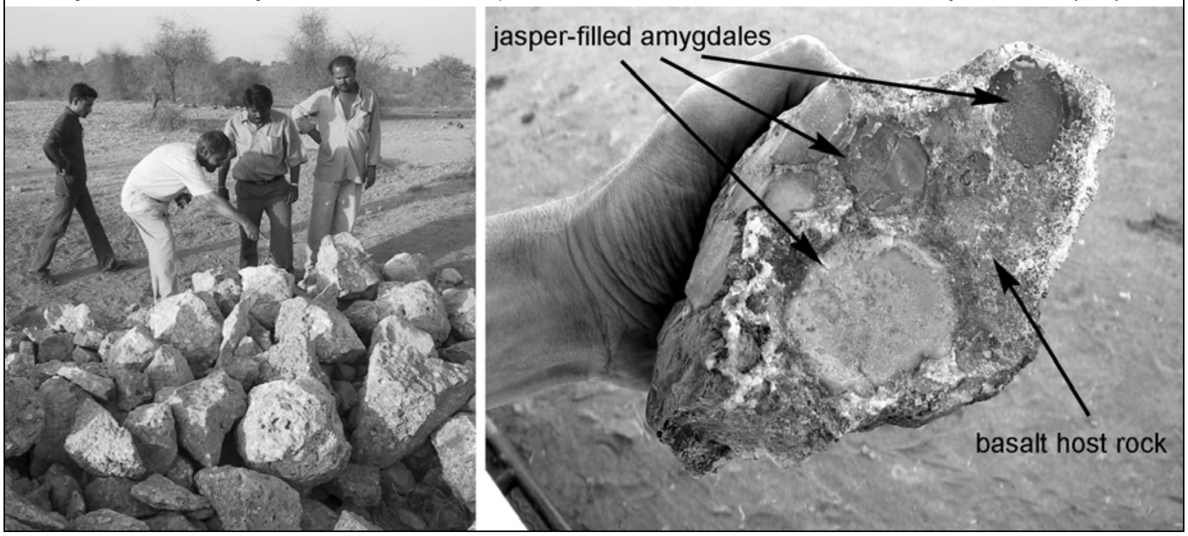
Geology and potential sources of agate in the Greater Indus region and beyond

Even after centuries of study, "the origin of agate remains incompletely understood" (Götze et al. 2001: 527). Nevertheless, a brief overview of what is known about the stone's formation and the primary and secondary geologic contexts in which it is found is useful for the upcoming outline of the its potential sources in the Great Indus region and beyond.

The formation of agate and agate deposits

Agates are translucent microcrystalline sedimentary rocks that form when silica precipitates in cavities within some type of host rock. The mechanisms behind their growth, frequent banding and other distinctive characteristics are the subjects of much debate (for detailed discussions and different views see Fallick et al. 1985; Heaney and Davis 1995; Merino et al. 1995; Moxon 1996; Pabian and Zarins 1994; Wang and Merino 1990, 1995). The rocks in which agates form may also be sedimentary (limestone, dolomite, claystone) but they are more commonly igneous (Luedtke 1992: 31-32; Pabian and Zarins 1994: 7). As certain types of volcanic lavas and tuffs cool, cavities (vesicles) form within them that later become filled in with secondary minerals like calcite, crystalline quartz and/or microcrystalline quartz – i.e, agates and jaspers. The filled cavities are called *amygdales* and the igneous host rocks containing them are described as *amygdaloidal* (Lapidus and Winstanley 1990: 24-25). A good example of this primary geologic context for agates and other microcrystalline silicates would be the "highly amygdaloidal" volcanic trap (basalt) rocks Fedden described (1885: 20, 62) in Gujarat's Saurashtra Peninsula (Figure 8.4). Although I encountered only jasper-filled amygdales (Figure 8.1) during my visit to the area, Fedden reported agate, moss agate and chalcedony in the region to the northwest of Rajkot.

Figure 8.1: Examining quarried, jasper-filled amygdaloidal basalt (*right*) near Khokhari Village, Rajkot District, Gujarat with Dr. Kuldeep Bhan and Arun Malik, M.S. University, Baroda (*left*)



As their host rocks erode, loosened agates (many retaining the nodular shapes of the cavities in which they formed) fall away. These then may be carried by fluvial action or other processes and end up in a range of secondary geologic contexts. In Gujarat at least (*personal observation*), it is not uncommon to encounter agate nodules or fragments when walking across the fields of India's famously rich "black cotton soils," which formed due to the decomposition of the basaltic rock of the Deccan Traps (Hegde 1989). In other places, such as sources that I will shortly discuss in eastern Kutch, all remnants of host rocks have disappeared leaving behind only loose "agates … so numerous as sometimes to form a coarse gravelly layer on the surface" (Wynne 1872: 116-117). Loose agates, often carried far from their original host formations, can be found in the beds of certain rivers, streams, nalas and wadis across South Asia, the Iranian Plateau and Arabia. In some places, fluvially transported microcrystalline silicates have been deposited and reconsolidated. The famous Ratanpur area sources are part of the early Miocene epoch conglomerate called the *Babaguru Formation* (Gadekar 1977). P.K. Chatterjee noted (1963b: 166) that

"chalcedonic silica, carnelian, chalcedony, chrysophrase, plasma, bloodstones, onyx, jasper, agate jasper, flint, chert, etc … [all] occur" within it.

It was extensive and materially diverse secondary agate deposits like the Babaguru Formation that initially caused me to be skeptical about whether or not it was possible to source this variety of stone. That particular formation is thought to be the remnant of a "fluvial delta" (Gadekar 1977: 555), most likely of a river that drained the west-central Deccan Plateau, not unlike the Narmada River does today. Agates and other microcrystalline silicates deposited within it could, therefore, have come from primary sources occurring over an enormous geographic area. Moreover, the Deccan Traps from which those stones eroded are not a homogenous geologic unit but rather succession volcanic events (see Sukheswala et al. 1972: Fig. 2a for a diagram depicting the layered amygdaloidal basalts of the western Deccan Traps). The Babaguru Formation might well then contain agates that formed in multiple basalts of slightly different ages and chemistries. As I stated in the introduction, it has thus far been possible differentiate Ratanpur agate samples from those of other deposits in Gujarat and elsewhere. It is important to realize, however, that as additional sources are analyzed, particularly from other locations in the Deccan Traps, this *may* become increasingly more difficult.

Potential Harappan agate sources

In this section, the agate sources that Harappans potentially may have had access in the Greater Indus region (Figure 8.2) and beyond (Figure 8.3) are outlined. We begin with an overview of Gujarat and then briefly examine deposits elsewhere in the Deccan Traps. Minor agate occurrences to the west and north of the Indus Valley are then discussed

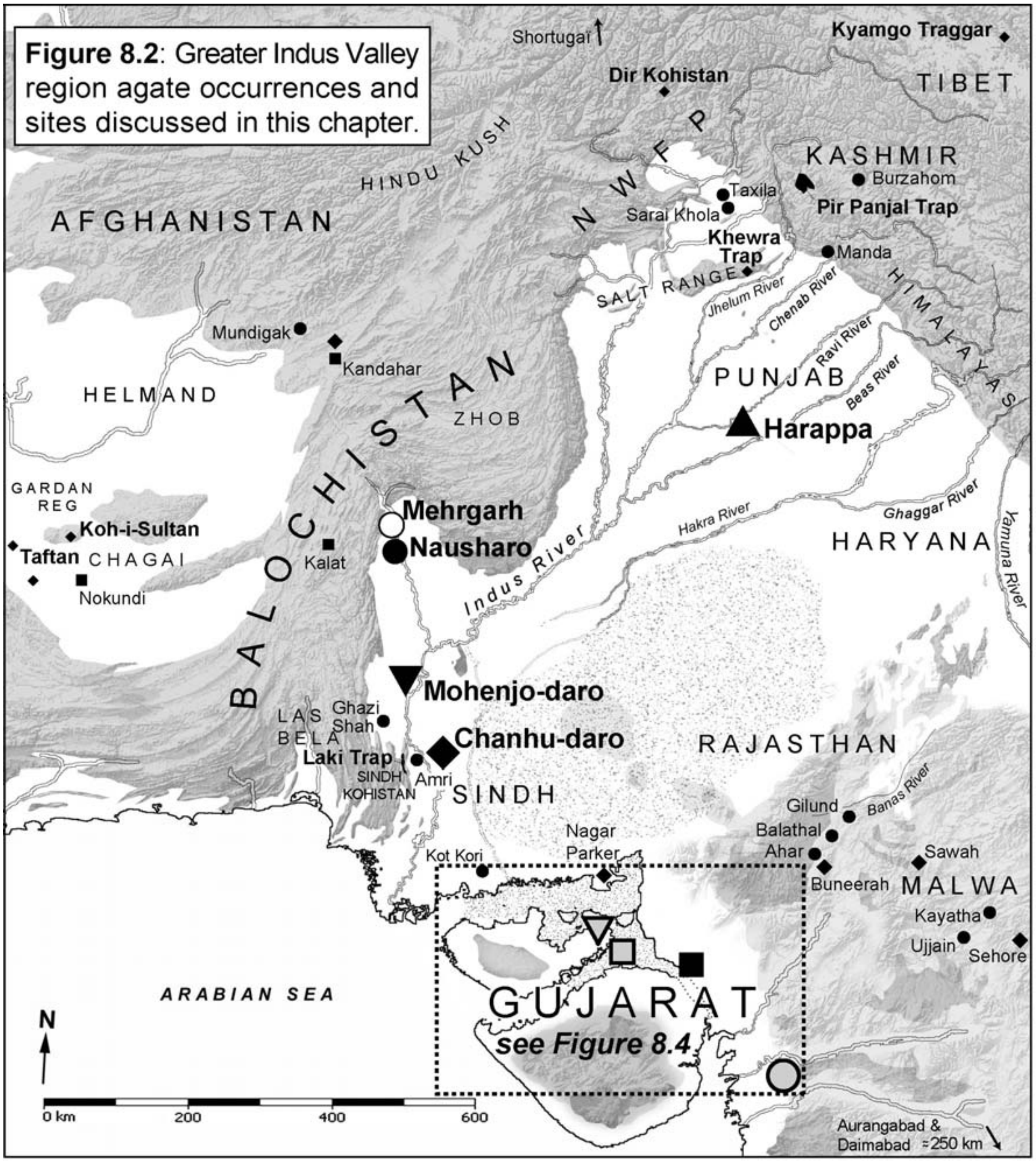


Figure 8.2: Greater Indus Valley region agate occurrences and sites discussed in this chapter.

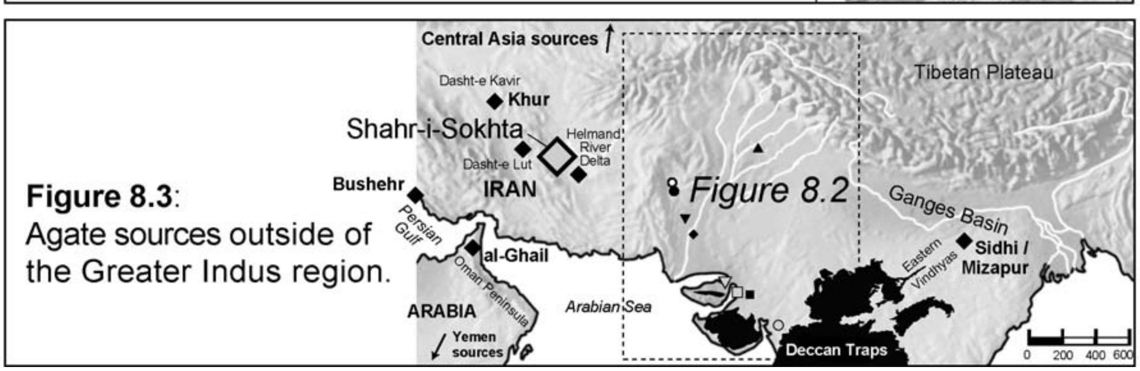


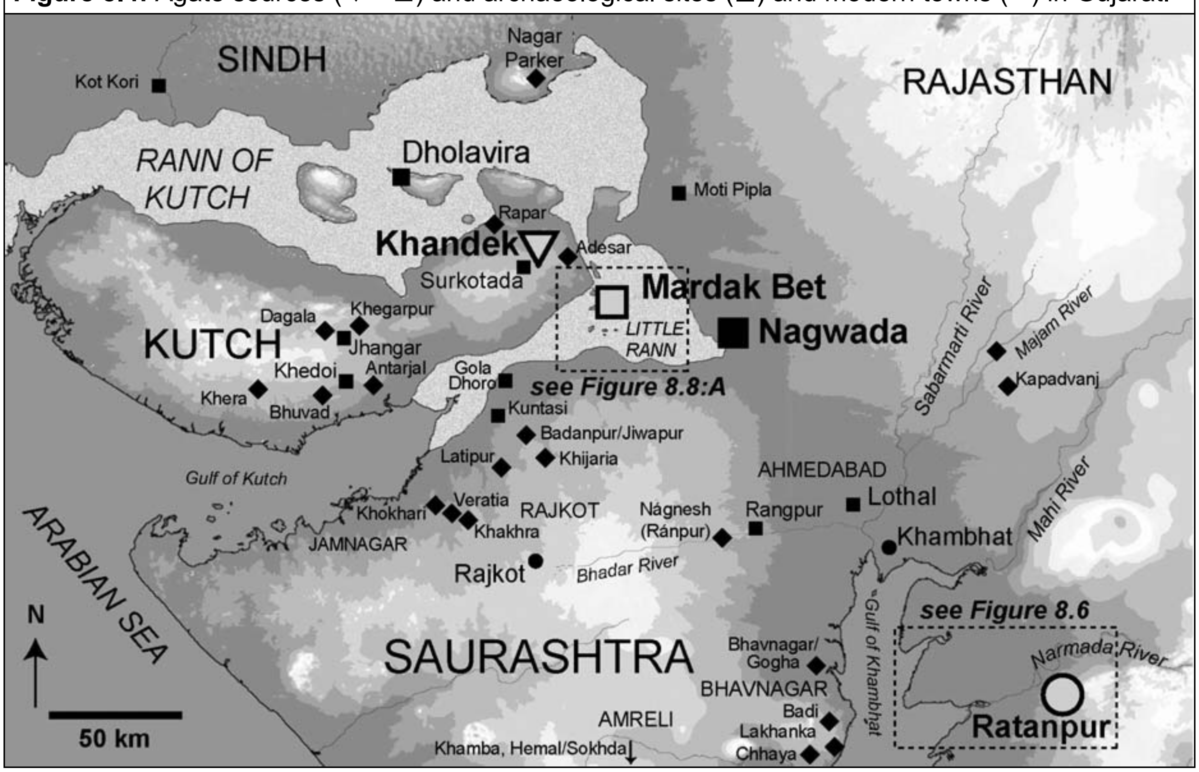
Figure 8.3: Agate sources outside of the Greater Indus region.

followed by potential sources in regions that Indus Civilization peoples had clear contacts with such as Afghanistan, southern Central Asia, the Iranian Plateau and eastern Arabia.

Agate deposits in Gujarat

There are a number of reasons why Gujarat (Figure 8.4) is assumed to have been an important source area, perhaps even the primary source area, for the agates used by Indus Civilization peoples. Firstly, Harappans were present there; often (as I show below) in very close proximity to some significant occurrences. In fact, ornamental microcrystalline silicates were probably among the resources (some other being marine shell, salt and pasturage) that attracted them to the region in the first place. Secondly, although occurrences of agate can be found in many parts of Asia, the extent, diversity and sheer richness of sources in Gujarat is unparalleled. The region could aptly be characterized as

Figure 8.4: Agate sources (◆ ○ □) and archaeological sites (■) and modern towns (●) in Gujarat.



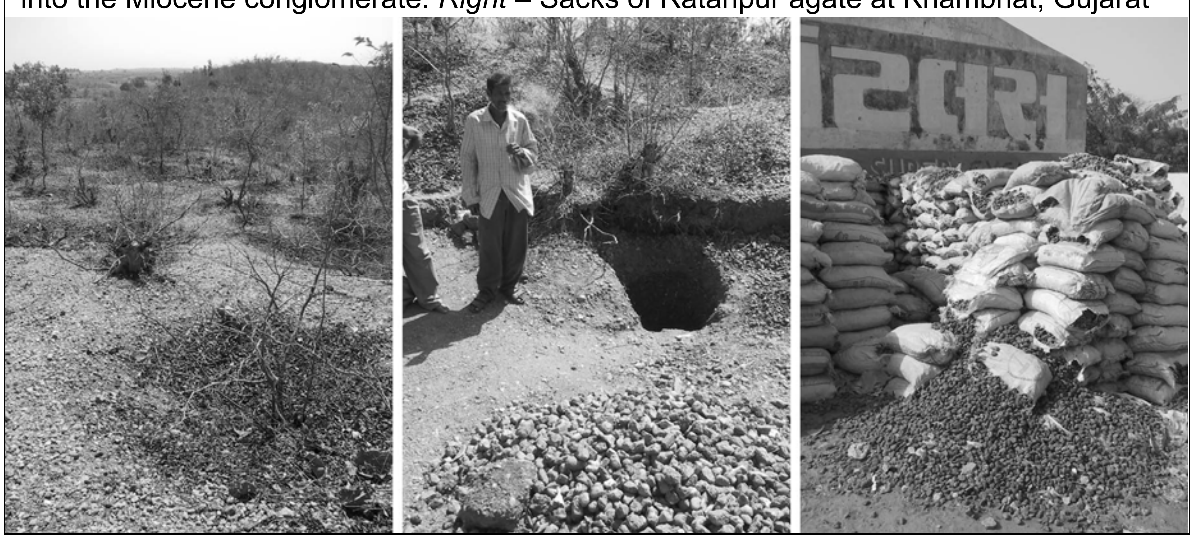
the "Saudi Arabia" of agate. Lastly, Gujarat was a historically important source area. Greek (McCrindle 1885: 77, 334; Schoff 1912: 42), Mughal (Khan 1756: 250) and early European colonial (Barbosa 1517: 66-67; Foster 1906: 52, 178) records all make reference to the agate resources there. The city of Khambhat (Cambay) has been a major center for the manufacture of agate ornaments since at least the 16th century (Arkell 1936; Campbell 1880: 206-207) and the traditional methods still employed there have been the subject of several ethnoarchaeological studies (Kenoyer et al. 1991, 1994; Possehl 1981; Roux 2000).

Throughout the historic era, the preeminent agate source within Gujarat has been the deposits around Ratanpur (Figure 8.6) in the southeast part of the state (Allchin 1979a; Ball et al. 1881: 506-507; Bose 1908; Francis 1983; Sahni 1948). This review begins there.

Southeastern Gujarat – Ratanpur area deposits

Among the low hills (Figure 8.5 *left*) around the village of Ratanpur, Bharuch District, Gujarat, there are hundreds of agate mining pits and shafts (Figure 8.5 *middle*) sunk into the Miocene conglomerate of the Babaguru Formation. Although these workings

Figure 8.5: Left – Pitted, agate nodule covered surface at Ratanpur. *Middle* – mine shaft into the Miocene conglomerate. *Right* – Sacks of Ratanpur agate at Khambhat, Gujarat



are often referred to as the “Rajpipla” deposits/mines (as they were within the confines of that princely state prior to 1947), “Ratanpur” is a more appropriate designation (Ball 1886: 238). Mining locations having published geographic coordinates (Chatterjee 1963a: 166; Insoll et al. 2004: 1162) are plotted on Figure 8.6. Trivedi noted (1964: Map 2) most of these localities, as well as around a half dozen others, in his review of the Khambhat bead industry, which to this day consumes tons of Ratanpur agate (Figure 8.5 *right*). All occur within fifteen kilometers of the hilltop tomb/shrine of Gori Pir (or Baba Ghor) – a Muslim saint who is said to have come from Africa in the 15th century and established bead-making operations at nearby settlements such as Limodara (Francis 1986; Kenoyer and Bhan 2005). M.R. Sahni (1948: 248-250, 253) noted that agates could also be obtained from the beds several small rivers (the Karad, Kaveri and Amravati) southwest of the Ratanpur area as well as to the east along the banks of the Narmada River near Rajpipla town. The nodules found in the former are said to be “rarely, if ever, of large size” (ibid.: 253). Those near Rajpipla, while larger, tend to be composed of clear chalcedony (*personal observations*).

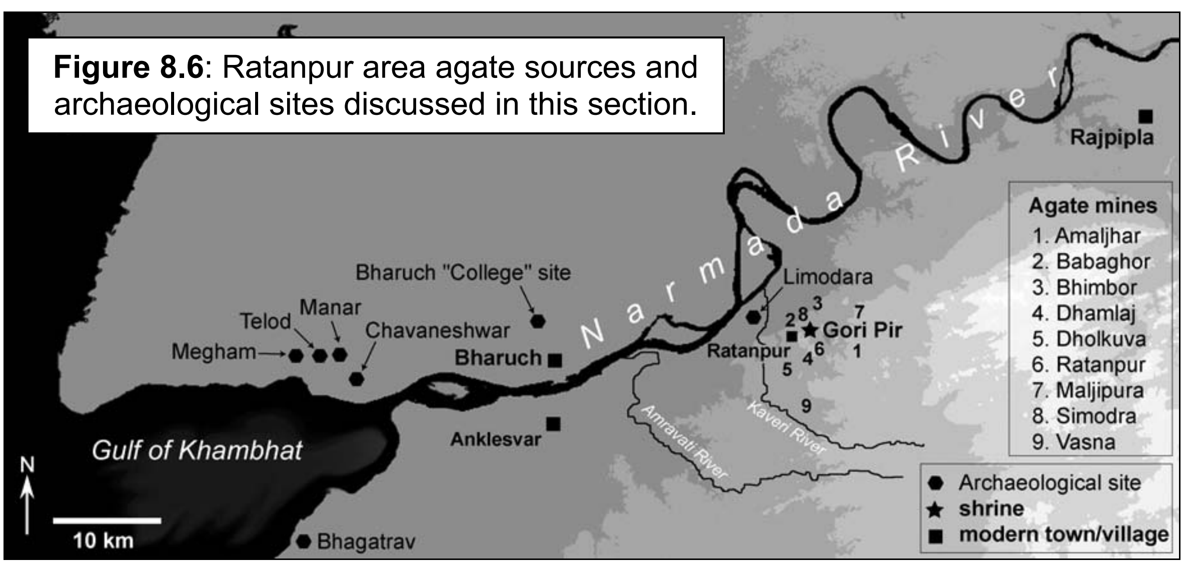


Figure 8.6: Ratanpur area agate sources and archaeological sites discussed in this section.

Samples for this study were collected from pits, shafts and tailings along a three kilometer zone extending from the base of Gori Pir Hill south-southeast to point #6 on Figure 8.6. Because the Babaguru Formation is a materially diverse secondary context agate deposit (discussed above), an attempt to assess geochemical variation across that zone was deemed to have little utility. All samples from this occurrence are, therefore, treated as coming from a single source, which is simply designated "Ratanpur."

It is unclear if Harappans might have had direct access to agate from the Ratanpur area deposits. Lothal – the nearest site that is inarguably an Indus Civilization settlement, is located around 130 km to the northwest of Gori Pir Hill. A handful of prehistoric sites are encountered as one moves west from Ratanpur toward the mouth of the Narmada River. Possehl identifies these as "Sorath Harappan" settlements in his *Gazetteer of Indus Age Sites* (Possehl 1999: Appendix A). If Indus Civilization peoples did acquire Ratanpur agate then doing so likely entailed interaction with the residents of these sites (or of other similar sites in the area) regardless of whether or not they were fellow Harappans or members of a separate, locally distinct cultural phase (recall the discussion on pp. 91-92).

Northern Gujarat

The agate sources of northern Gujarat would have been the ones most directly accessible to Indus Civilization peoples. There are number of occurrences (at Antarjal, Bhuvad, Dagala, Khera and Khegarpur) reported in central Kutch (Geological Survey of India 2001a: 47). These sources, which have not been described in detail but are likely derived from nearby outliers of the Deccan traps, are located in close proximity (less than 10 km) to Harappan settlements like Jhangar (Joshi 1990: 418) and Khedoi (IAR 1976-77:

15). Toward the east, A.B. Wynne noted (1872: 72-73) that the "agate-bearing laterites of North-Eastern Kutch are far removed from the stratified [Deccan] traps, resting to their entire exclusion upon Jurassic rocks … the source of the agates rather widely disseminated in them is somewhat mysterious, there being no evidence that the bedded traps ever existed in that part of the district, nor does any outlier of them occur within a distance of about forty miles" (≈ 65 km). Occurrences of this type are found around Adesar (Geological Survey of India 2001a: 47), northwest of Rapar on the eastern shore of the Great Rann (Merh 1995: Figure 17) and near Khandek village. A deposit on Mardak Bet in the Little Rann (Trivedi 1964: 10-11) is, however, associated with trap rock (Satyanarayana and Narasimha Rao 1955: 88). The latter two sources mentioned were sampled for this study.

Khandek, Eastern Kutch

The Khandek agate source (Figure 8.7 *left*) was first brought to my attention by R.S. Bisht, the excavator of the Harappan city of Dholavira, which is located some 70 km to its west-northwest on the island of Khadir. Ravaji Solanki – the local stone expert (pattarwala) at Dholavira provided directions to Khandek village and his brother Narsingh,

Figure 8.7. Loose agates beds at Khandek, eastern Kutch, Gujarat



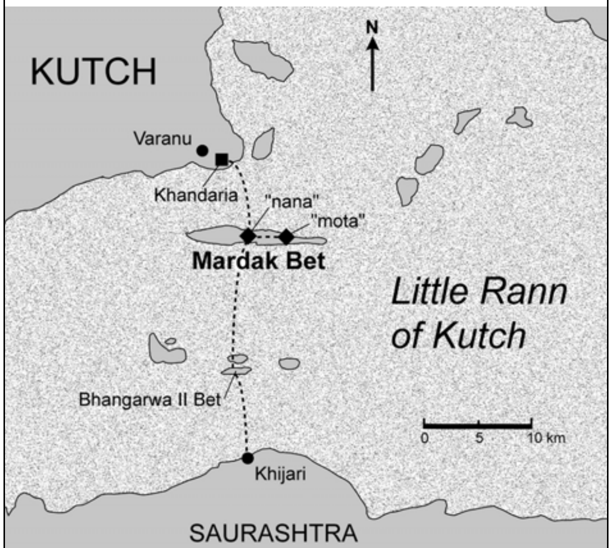
who resided there, guided me to the source itself (located at N 23° 38' 28", E 70° 52' 22"). A pavement-like layer (Figure 8.7 *right*) of loose agates (natural carnelian, yellow-brown agate, clear chalcedony, moss agate) and other microcrystalline silicates (red, green, brown and variegated jaspers) covers an area of perhaps four hectares (roughly 200 x 200 meters) just east of the village. This source is located around five kilometers from the small fortified Indus Civilization settlement of Surkotada (Joshi 1990). Although no clearly prehistoric workings or cultural materials were identified, numerous "window" flakes (pieces of cortex that were struck from nodules in order to observe the quality of the agate inside) were found that indicate it had been exploited for materials at some time in the past.

Mardak Bet, Little Rann of Kutch

The agate deposits on the island (bet) of Mardak, in the salt marsh southeast of Kutch known as the "Little Rann" (Figure 8.8 A), can be difficult to reach due to seasonal flooding of the area surrounding them (Trivedi 1964: 11). A sampling trip with Arun Malik (a PhD student at Maharaja Sayajirao University) in early 2003 ended with us stuck in the mud within sight of the island (Figure 8.8 B). A second attempt (this time with Malik and Dr. Kuldeep Bhan) later that same year just prior to the summer monsoons was successful.

Mardak Bet is a thinly-shaped, east-west oriented island around 12 km in length with a maximum width of about 1.25 km. The agate beds are found in two main areas. The most extensive is located near the island's constricted mid-section, which Malik designated "nana." Another occurs 3 km to the east, around the base of its highest hill (≈ 40 m above the salt flats), which was designated "mota." A wide range of microcrystalline silicates are found at both locations. Brownish-gray agate is by far the most abundant type

Figure 8.8: A. Little Rann of Kutch, Gujarat



B. Mardak Bet (arrow) across the Little Rann



C. Pit in agate bed at "nana" Mardak Bet



but nodules of natural carnelian, clear chalcedony and moss agate are not uncommon. Red, green, yellow-brown and variegated jaspers (including bloodstone) are also found. Mardak Bet is the only source visited at which I have encountered a distinctive type of brown and white parallel-banded agate-jasper that was used by beadmakers at both Dholavira (*personal observations* 2007) and Harappa (for an example see Kenoyer 1998: Figure 6.44).

No prehistoric settlements are known to exist on Mardak Bet and no ancient workings in the island's agate beds were identified during our short visits to them. Mining pits (Figure 8.8 C) and sorting areas related to modern extraction activities (Singh 1999: 216; Trivedi 1964: 10-11) have likely obscured any evidence of earlier ones. There are, nonetheless, indications that ancient peoples did exploit these deposits. Numerous agate and jasper

flakes, some with a heavy patina suggesting great antiquity, were found on the hillside at "mota" Mardak Bet. Similar flaking debris was also observed 12 km to the south on Bhangarwa II Bet. That small island was likely a processing point for raw material obtained at Mardak Bet as there are no agate sources on or nearby it. Finally, I have been informed by R.S. Bisht (*personal communication* 2004) that agate and jasper artifacts visually identical to the material occurring at Mardak Bet (which he has explored firsthand) are evident at the Harappan site of Khandaria (Bisht 1989a: 267), which is located less than 10 km away near the village of Varanu on the northern shore of the Little Rann.

Eastern Gujarat and Saurashtra

There are a number of other agate occurrences in Gujarat that, even though they were not sampled for this study, should be noted as potential Harappan sources. Multiple types of microcrystalline silicates (including some that can be heat-treated to produce carnelian) occur around Kapadvanj, in the eastern part of the state (Campbell 1879: 15). Nodules as large as ten pounds (≈ 4.5 kg) were once gathered near that town as well as from the bed of the Májam River, some twenty kilometers to the north (Campbell 1880: 199-200). This source area is located approximately 100 to 110 km northeast of Lothal.

A wide range of microcrystalline silicates, both occurring in and eroded from amygdaloidal basaltic rocks of the Deccan Traps, are found across the Saurashtra Peninsula (also known as Káthiáwár). Below I discuss just a few of the more notable occurrences.

A black and white veined material that was once the "most valued Cambay agate" (Campbell 1880: 200) occurs some 50 km west-southwest of Lothal around Ránpur village in the Ahmedabad District (not to be confused with the site of Rangpur [Rao 1963], which

lies 22 km east of that settlement along the Bhadar River). The geographic coordinates provided by Chatterjee (1963a: 166) suggests that the actually source of this stone is probably at nearby (5 km east) Nágnesh village where an exposed "bed of sphæroidal felsite, whose nodules have a nucleus of chalcedony" was reported (Fedden 1885: 26).

Miocene rocks in the vicinity of the towns of Bhavnagar and Gogha in the Bhavnagar District are "agatiferous" and resemble the conglomerates of the Ratanpur area (Mohan and Chatterji 1956: 351; Fedden 1885: 110), which lay directly opposite to them across the Gulf of Khambat. Very similar conglomerates containing "agate, chalcedony, flint, jasper, etc." are also reported farther south near Lakhanka and between Badi and Chhaya (Gujarat State Gazetteers 1961b: 22). Still farther south, in the southern part of the Amreli District (not pictured on Figure 8.4), "milky white chalcedony and agate form geodes in the traps near Khamba, while pebbles of agate and chalcedony are found loose in the nala between Hemal and Sokhda" (Gujarat State Gazetteers 1961a: 17).

The Rajkot and Jamnagar districts of northern Saurashtra are especially rich in ornamental microcrystalline silicates. Chatterjee compiled (1963a: 167 – from Fedden 1885 and other sources) information on a number of locations (Khijaria, Latipur, Jiwapur, Badanpur, Khakhra, Varatia) at which agate, moss agate and chalcedony occurred, both as loose nodules and in amygdaloidal trap rock. The jasper source near Khokhari village that was highlighted earlier (Figure 8.1) is also located in this region as are numerous ancient settlements including Kuntasi (Dhavalikar 1992) and Gola Dhoro (Bhan et. al 2004). Storage bins containing sorted blocks of variegated jasper found at the latter site provide evidence that Harappans were acquiring microcrystalline silicate resources from this region.

Agate deposits elsewhere in South Asia

Gujarat may have been the richest agate source area in South Asia but it was not the only one. In this section, I review other potential sources in the Subcontinent with a particular emphasis on those in and adjacent to Greater Indus region.

Peninsular and Central India

In addition to the agate deposits of Gujarat, P.K. Chatterjee noted, in his *Annotated Index of Indian Mineral Occurrences* (1963a: 165-168), sources in the states of Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Mysore, Orissa, Rajasthan and Uttar Pradesh. There is no need to review all of them in detail here as most are unlikely to have been utilized by Indus Civilization peoples. For example, the varied agate deposits in the Deccan Traps around Aurangabad in central Maharashtra are important raw material sources for Khambhat lapidaries today (Vidale 2000: 42). Those same occurrences might have even been exploited by the Late Harappan peoples who were dwelling around 80 km from them at Daimabad (Sali 1984). However, they are unlikely to have been utilized to any great extent (if at all) by Indus Civilization beadmakers. To my knowledge there are few (if any) types of ornamental microcrystalline silicates at Aurangabad or elsewhere in Peninsular India that are not also available in Gujarat. There would, therefore, be little reason for Harappans in the Indus Valley proper to bypass source areas like Kutch, Saurashtra or Ratanpur, in order to obtain agates from that region. They were even less likely to have acquired such materials from still more distant deposits in southern India. The agate occurrences of Central India, being comparatively near the Greater Indus region, would have been much more viable alternate sources for residents of Harappa.

Chatterjee noted (1963a: 168) that “agate, jasper, carnelian, moss [agate] and onyx are common in the beds of the Banas and other rivers” in eastern Rajasthan. In this same general area, Hardie described (1829: 117-119) primary context agate-jasper at Sawah and at Buneerah. Malwa-Rajasthan Tradition Ahar-Banas culture complex (Shinde et al. 2005) peoples at settlements like Gilund, Balathal and Ahar would have been in close proximity to these occurrences. Slightly farther to the east, the agate sources of the Sehore-Bhopal region in western Madhya Pradesh (Chatterjee 1963a: 168) may have been among those exploited by beadmakers working at Ujjain during the historic era (Banerjee 1959) and at nearby Kayatha during the Chalcolithic Period (Ansari and Dhavalikar 1971). Harappan-like large storage jars and a cache of 40,000 steatite microbeads (ibid.: 338, 342, Plate 7) recovered in Period 1 (ca. 2000 to 1800 BC) levels at the latter site indicate that people dwelling there had contacts with later phase Indus Tradition peoples. It is not clear if those links extended from Kayatha north-northwest toward Harappan/Late Harappan groups in the Upper Indus Basin/Gangetic Basin region or southwest toward those in Gujarat. What is clear is that trade networks connecting the Malwa Plateau region with the northern Subcontinent (the Ujjain to Taxila route – Eggermont 1966) were firmly in place by the early historic era. The storage jars and steatite beads from Period 1 at Kayatha may represent the initial establishment of those northern networks. This is important for the current discussion because it was around this time that interaction between peoples of the northern and southern reaches of the Greater Indus region diminished (Kenoyer 2005b), thus making the microcrystalline silicate resources of Gujarat unavailable to beadmakers at northern cities like Harappa. The agate deposits of the Malwa Plateau region might have

become important new sources for them when this happened. As the demographic center of gravity in the north shifted toward the Gangetic Basin during the first half of the second millennium BC (Possehl 1997b), Late Harappan people might have begun to utilize agate from sources even farther to the east, such as those in the Sidhi-Mirzapur region (noted on Figure 8.3) of the eastern Vindhya Range (Chatterjee 1963a 168; Srivastava et al. 1983).

Northern deposits

Agate deposits located in the mountainous regions north of the Upper Indus Basin are small in size, widely scattered and, in certain instances, extremely remote. Most are associated with volcanic rocks. Two occurrences – one in the Khewra Trap of the eastern Salt Range and the other in the Pir Panjal Trap of western Kashmir, were previously (pp. 257-258) noted as possible sources for the purplish-colored chert/chalcedony found in Early Harappan levels at Harappa. "Small geodes of reddish quartz and chalcedony" were observed (Wynne 1878: 75) in the former formation while "pear-shaped amygdules of chalcedony, reaching to two or three inches in length" were reported (Lydekker 1883: 218) to occur in the latter. In the NWFP, agate nodules derived from with island-arc volcanics are found in the Dir Kohistan area (Kazmi and Jan 1997: 477). Their appearance has not been described, however. Godwin-Austen reported (1867: 362) that "fine agates and cornelian are to be found in a small ravine" at Kyamgo Traggar, north of Pangong Lake not far from the Tibet-Kashmir border. This occurrence lies over 5100 m above sea level.

It is quite possible that agates from these northern sources found their way into bead workshops at Harappa. In this dissertation, I show that both Early Harappan and Harappan residents of the site were acquiring other raw materials derived from sources in the Salt

Range (chert and alabaster) and western Kashmir (lead and, perhaps, alabaster). The Dir agate source area lies along what may have been a route from the Indus Valley to northern Afghanistan and the Harappan outpost of Shortughaï. Finally, extreme elevation evidently did not impede Northern Neolithic peoples, such as those periodically dwelling at Burzahom in the Kashmir Valley, from crossing the plateau of Tibet during the prehistoric period (Xu 1991). Early Harappans and/or Harappans at settlements in the Himalayan foothills such as Sarai Khola and Manda might have indirectly acquired agates from remote sources like Kyamgo Traggar through interaction with those northern highlanders.

Sindh and Balochistan

The agate deposits of Sindh and Balochistan, like those in the north, are small and sporadic. A source is reportedly located at Nagar Parker (Kazmi and Jan 1997: 477) in the southeastern corner of Sindh (noted on figures 8.2 and 8.4) near the northern shore of the Great Rann of Kutch. The material found there and its mode of occurrence has not been described but it is quite possibly related to the agate deposits directly to the south on the opposite side of the rann in eastern Kutch. Although no prehistoric sites are reported in the immediate vicinity of Nagar Parker (to my knowledge, no survey has yet been conducted there), toward the west a number of Indus Civilization settlements (Baloch 1973), including Kot Kori (Khan 1979), have been identified in the southern part of Sindh.

In the northern part of the Sindh Kohistan's Laki Range – a north-south running chain of hills that forms part of the western boundary of the Indus Valley, W.T. Blanford first reported (1869: 5-6) "trap" rock that is "slightly amygdaloidal and contains agates." He later identified these thin, weathered beds of basalt and volcanic tuff as distant outliers

of the Deccan Traps (1879: 36-37). Unfortunately, like many geologists then and now, Blanford did not see fit to describe in detail the appearance (size or color) of the actual agate nodules/amygdales within them and no description has since been published. Nevertheless, this occurrence should be regarded as an important potential source due of its correlation to the Deccan Traps and because of its close proximity to a number of Early Harappan and Indus Civilization settlements including Amri (≈ 10 km east), Ghazi Shah (≈ 45 km northwest) and Chanhu-daro (≈ 40 km east). Agate beadmaking was a major industry at Chanhu-daro (Mackay 1938: 52; Sher and Vidale 1985) and a few examples of "chalcedony" were among stone tools debris recovered at Amri (Cleland 1977: 84).

Most ornament-quality microcrystalline silicates in areas of Balochistan adjacent to the Indus Valley are red, green and variegated jaspers associated with ophiolite sequences, such as those in the Zhob and Las Bela districts (*personal observations*). Translucent and semi-translucent varieties do sometimes occur, however. Charles Masson noted (1844: 463) that "agates … are found in the hills east of Kalat" in central Balochistan but he did not describe them. Although some such stones from this area might have found their way down to Indus Tradition peoples at plains sites like Mehrgarh and Nausharo (≈ 100 km to the west-northwest), they probably were not of especially good quality.

Agates occurring in western Balochistan's Chagai District are a different story. Excellent quality examples can be found within and eroding from the andesitic lavas of the region's volcanic formations. Of these agates, Heron [Crookshank] wrote (1954: 131) that "they are as good as the similar stones from Broach [Ratanpur], India, and … often display novel patterns not found among the Indian stones." An example of one – collected near

Figure 8.9: Brown and white banded agate from Taftan railway station, Chagai District, Balochistan.

GSP-Quetta Museum, Case 41



Taftan railway station and now on display at the Geological Survey of Pakistan's museum in Quetta, can be seen in Figure 8.9. Others are reported at the extinct volcano known as Koh-i-Sultan (Iqbal et. al 1993) and in the desert 45 miles (72 km) west of Nokundi (Heron [Crookshank] 1954: 131). These agate sources are particularly important because of their proximity to the rich copper deposits and ancient smelting areas of the Chagai District and the adjacent Gardan Reg region of southwestern Afghanistan (Dales 1992; Vredenburg 1901). Analyses conducted for this dissertation indicate that some copper ore fragments at Harappa likely came from sources located to the west of the Indus Valley (see Chapter 12). If those western sources happened to be in the Chagai District (this is not yet demonstrated but it is a distinct possibility) then agates from the area might have been acquired as well.

Agate deposits beyond the Greater Indus region

In this final section, I provide a brief overview of agate occurrences in Afghanistan, Central Asia, Iran and Arabia – lands outside of the Greater Indus Region with which Harappans had demonstrated contacts (see pp. 92-93).

There is not a great deal of published information regarding the agate occurrences of Afghanistan. In their review of the natural resources of Mundigak – a Bronze Age settlement in the southern part of that country, Jarrige and Tosi mentioned (1981: 137) that various kinds of microcrystalline silicates "are available in the talus slopes of the Hindu

Kush in form of pebbles of different sizes." Closer sources were available to the residents of that site, however. Just 45 km to the southeast, C.L. Griesbach reported (1881: 52, 59) amygdales filled with agate and carnelian in the volcanic trap rock around Kandahar city.

Agate sources in Central Asia, although remote, bear mentioning here because of the clear contacts that Harappans had with BMAC peoples, both in the southern part of that region (Hiebert 1995) and in the Indus Valley (Parpola 2005). Gem quality chalcedony is reportedly found in the Turkestan Range of Uzbekistan (Clarke 1970: 534) and agates are mined today in Tajikistan (Nokleberg et al. 2005: 78). Rich deposits also occur in the Irtysh and Pavlador regions of Kazakhstan (Bryksina et al. 2001; Yerofeyev and Matsui 1986).

Moving now to sources in Iran, Whitehouse noted (1975: 130) that "nodules of red and orange carnelian erode out of Tertiary sediments" on the Bushehr Peninsula. This occurrence's location adjacent to the Persian Gulf might have made it an important source for consumers in ancient Mesopotamia. However, the "most celebrated Iranian agate localities are in the central and eastern" part of the country (Nazari 2004: 21). Around the Khur area, primary context banded agate nodules occur within tuffaceous andesite (ibid.). Extensive secondary context deposits can be found in Iran's broad salt deserts (dasht) and inland deltas. The explorer Henry Savage Landor marveled (1902: 79) at the "handsome agates" and other colorful stones spread across the wastes of the Dasht-e Lut. Hakemi wrote (1997: 15) that "carnelian is found in considerable quantities in the Lut flood plain." Finally, Tosi noted (1969: 374) that "with regard to cornelian … numbers of little pebbles of this stone, with a diameter often exceeding 3 cm, may be collected along the dried out beds and ancient branches" of the Helmand River delta near the site of Shahr-i-Sokhta.

Lastly, at al-Ghail, near the northern tip of eastern Arabia's Oman Peninsula, Burkhart Vogt reported (1996: 112) that at outcrops bearing "clear traces of opencast mining and quarrying … banded agate and carnelian of different varieties and qualities appear in thick veins and are easily accessible." Although it may seem unlikely that raw material from this distant source was shipped all the way to bead workshops in the Indus Valley, Harappans did have a significant presence in this region and so the possibility cannot be completely ruled out. Agate-carnelian occurrences can also be found in central Yeman (Overstreet et al. 1985: 319). However, there is no evidence, at present, that Harappan interaction networks in Arabia extended that far to the south.

Section conclusion

There are several reasons why it was necessary to provide a full overview of agate occurrences in the Greater Indus region and beyond even though only three of the deposits discussed above were actually sampled and analyzed. Firstly, it allows the provenience study that follows to be put into perspective. Although the results of this study bode well for future research of this kind, it was important to make clear that they are based on the analysis of only a limited number of potential sources. Secondly, the overview will aid in the interpretation of the study's results. We will see that while most of the agate artifacts analyzed seem to be closely related to the one of the sources in the geologic dataset (described at the beginning of the next section), there are a handful that clearly do not. The possible provenience of those standouts can be better judged now that a broad picture of occurrences has been presented. Lastly, it needed to be shown (insofar as the published information made it possible) that all agate deposits are not the same. Like so many of the

other materials studied for this dissertation, the appearance, size and quality of microcrystalline resources vary considerably from occurrence to occurrence. Just because "agate" is reported at a particular locality does not mean that stone that Harappan beadmakers would have found suitable occurred there.

A geologic provenience study of agate artifacts from Harappa and five other sites

In this half of the chapter, I recount how agate artifacts from Harappa and five other Indus Tradition sites were analyzed (using INAA) and compared (using CDA) to samples from three sources in Gujarat and a set of artifacts from the site of Shahr-i-Sokhta that were treated as proxy samples for sources in eastern Iran. The main objective was to evaluate the widely held assumption that Harappan agate primarily came from Gujarat and that the principal sources within that state were the Ratanpur area deposits. Noting the agate occurrences at Mardak Bet and in eastern Kutch, Ratnagar had asked (2004: 146) "did the Harappan inhabitants of Dholavira know of these sources?" This was a good question. Seemingly, those agate occurrences should have been far more accessible to the Harappans of that city than the Ratanpur area deposits, which are located hundreds of kilometers to the southeast (recall Figure 8.4). Although no artifacts from Dholavira were available for this study, it was reasoned that if Gujarat was the principal region from which Indus Civilization peoples obtained agate resources, then it should be possible to indirectly address Ratnagar's question through provenience analyses of artifacts from other Harappan sites in northern Gujarat and the Indus Valley proper. Before detailing and interpreting the results of this study, the selection of source (and proxy source) samples for the geologic dataset are discussed and the agate artifacts that were analyzed are introduced.

Agate source and proxy source samples

For this study, agate samples were collected from the three potential sources in Gujarat – Mardak Bet (source code = GMB), Khandek (GKK) and Ratanpur (GRTP). Although material-wise, each of these secondary context deposits is extremely variable, the samples selected for analysis (figures 8.10 A to C) represent a narrow range of types. Most (but not all) are either natural carnelian or the type of yellowish-brown, iron-impregnated agate that will develop the red-orange hue characteristic of carnelian when heat-treated. Twenty samples from each source were selected (note that only 12 of the 20 from GMB and GKK are actually pictured on figures 8.10 A and B respectively). Earlier I described how agates collected from across a three kilometer-long zone at Ratanpur were treated as coming from a single source. The same will be the case for all samples acquired at GMB (even though the set contains agate from both "nana" and "mota" Mardak Bet) and GKK.

I was unable to visit any agate occurrences other than the three just discussed, which was unfortunate as it would have greatly benefited this study to include samples from a geologic source outside of Gujarat for comparison. A solution to this problem was provided by Dr. Massimo Vidale (l'Istituto Italiano per l'Africa e l'Oriente [IsIAO], Rome) when he generously granted me access to agate manufacturing debris he had collected from the surface of Shahr-i-Sokhta – a Bronze Age urban center in eastern Iran (Tosi 1982). These artifacts, which consisted of chunks of both variegated agate-carnelian and bluish-hued chalcedony (Figure 8.10 D), were, in all likelihood, derived from known occurrences (described in the previous section) near that site or in the general region. The decision was made to use the debris fragments as proxy samples for a "source" (source code S-i-S) in

Figure 8.10: Geologic source (and proxy source) samples analyzed for this study

A. Gujarat, Ratanpur (source code = GRTP)



B. Gujarat, Mardak Bet (source code = GMB)



C. Gujarat, Khandek (source code = GKK)



D. Iran, Shahr-i-Sokhta (source code = S-i-S)



eastern Iran. It is recognized that the 14 samples selected might not be from the same locality and that some samples, potentially all of them, might not even be from a source in Iran. Nevertheless, with those qualifications, they were included in the geologic dataset.

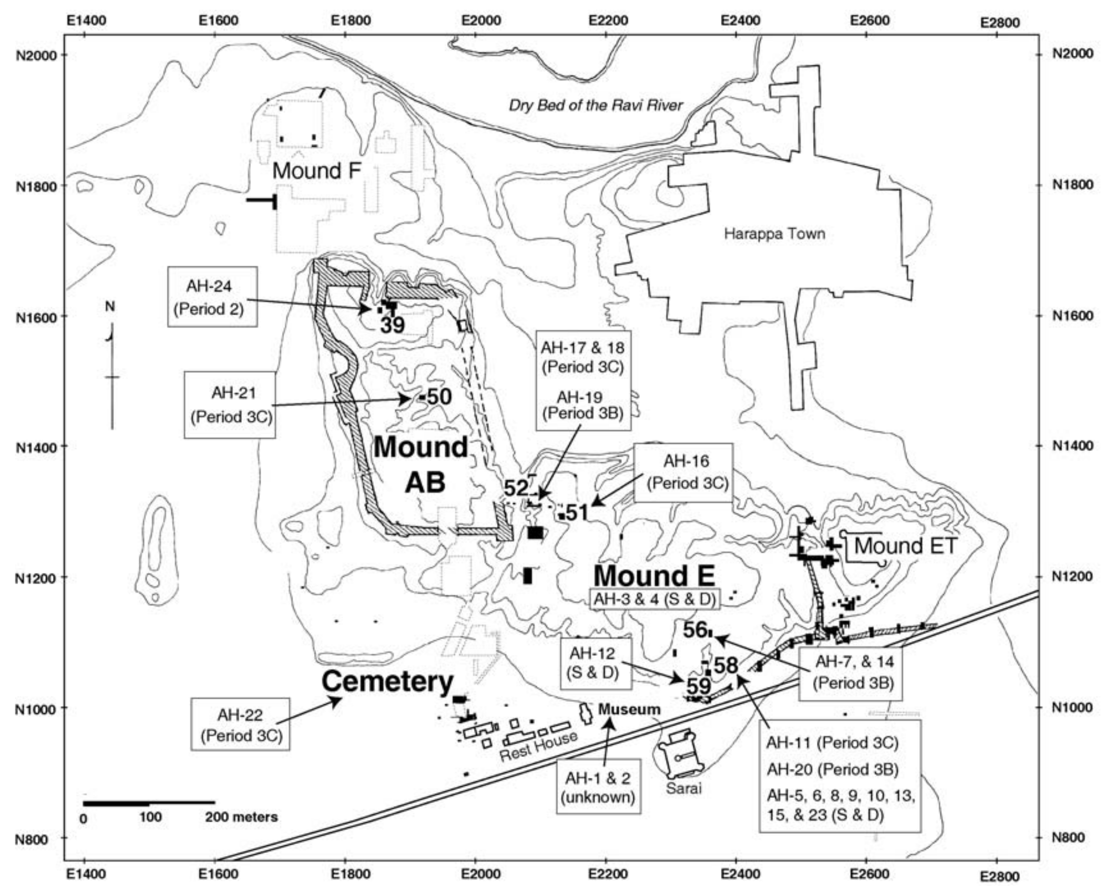
Agate artifacts

For this study, 24 agate artifacts from Harappa and 32 from five additional Indus Tradition sites were analyzed and compared to the geologic dataset outline above.

Artifacts from Harappa

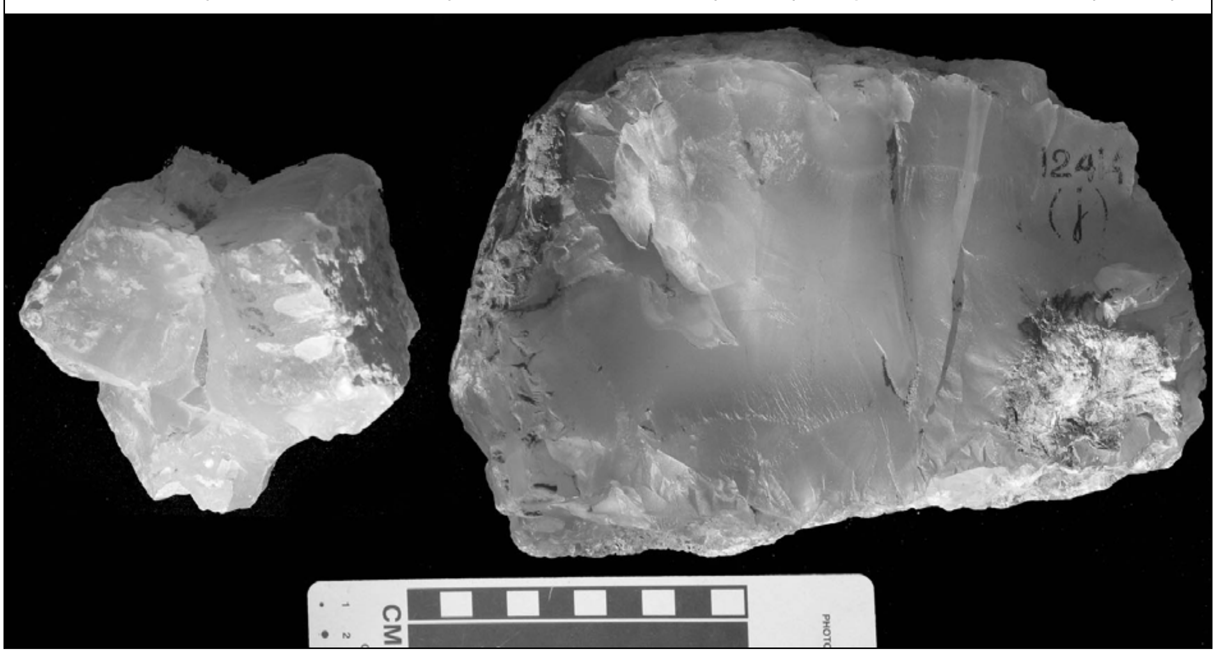
The 24 agate artifacts from Harappa that were selected for analysis come from various periods and parts of the site (Figure 8.11). They are numbered AH-1 to AH-24 for

Figure 8.11: Spatial and period-wise distribution of analyzed agate artifacts from Harappa.



this study. Their original HARP numbers and context information are listed in columns two and three of Appendix 8.5. Only 11 of the 24 artifacts were recovered from secure stratified contexts. One comes from Kot Diji Phase levels while the remaining ten come from Harappa Phase levels (three from Period 3B and seven from Period 3C). Nineteen of the 24 artifacts were recovered on mounds E or ET. Of the remaining five, two came from Mound AB and one from a layer of Harappan dump debris in the cemetery area. The exact provenience of two artifacts (AH-1 and AH-2) is unclear. They are agate-chalcedony nodule fragments (Figure 8.12) from pre-HARP excavations that had been stored in the Harappa Museum's Reserve Collection of large stone objects. In fact, these are the two biggest agate artifacts yet recovered at Harappa (AH-1 weighs approximately 0.7 kg and AH-2 weights around 4 kg). Given that they are from the excavations of the 1920s and 30s, it is most probable that they come from Harappa Phase levels either on Mound AB or F.

Figure 8.12. Two large agate nodule fragments from previous excavations at Harappa analyzed for this study. *Left* – HM 2397 (AH-1). *Right* – HM 12414 (AH-2)



The set of agate artifacts from Harappa (Figure 8.13 A) includes thirteen nodule fragments or flakes (AH-3 to AH 15) in addition to the chalcedony nodules just discussed. Examples of carnelian, yellowish-brown agate and semi-translucent chalcedony were selected. I have observed each of these types at all three of the potential sources in Gujarat.

The remaining items in the Harappa agate artifact dataset are all bead fragments. Eight are broken pieces of classic Harappan-style long-barrel carnelian beads. A complete example (which was not analyzed) is provided on the figure for comparison. Because this style of bead was only manufactured during the latter half of the Harappa Phase (J. Mark Kenoyer *personal communication* 2007), it is possible to say that the one example (AH-23) that was recovered from a non-secure context is very likely from either Period 3B or 3C. Importantly, agate-carnelian nodules large enough to make these long beads are rare. The little (≈ 3 cm) carnelian pebbles Tosi described (1969: 374) near Shahr-i-Sokhta would have definitely been too small. Nodules of sufficient size are known mainly to occur in Gujarat at Ratanpur, Kapadvanj and Mardak Bet (Trivedi 1963: 9-11). Although I did not observe any nodules bigger than about 7 cm at Khandek in eastern Kutch, in all likelihood any larger ones that had once been on the surface there were gathered up long ago.

A fragment of a circular-shaped carnelian bead (AH-24) from Period 2 levels on Mound AB rounds out the Harappa agate artifact set.

Artifacts from five other Indus Tradition sites

In addition to the proxy source samples from Shahr-i-Sokhta, Massimo Vidale kindly provided agate debris fragments related to his work on craft activity areas at the sites of Mohenjo-daro (Vidale 1987a) and Chanhu-daro (Sher and Vidale 1985) in Sindh. The

Figure 8.13: Agate artifacts from Harappa and five other sites analyzed for this study.



seven artifacts from Mohenjo-daro (Figure 8.13 B) were collected from among lapidary debris on the surface of the “Moneer” area and include examples of yellowish-brown agate, banded carnelian and chalcedony. Although it impossible to say with certainty, this debris probably dates to the latter part of the site’s Harappa Phase occupation. The seven artifacts from Chanhu-daro (Figure 8.13 C) closely resemble those from Mohenjo-daro and, although they are from the site’s surface, also likely date to the Harappa Phase.

Dr. Kuldeep Bhan (Department of Archaeology, Maharaja Sayajirao University, Baroda) generously provided three yellow-brown agate flakes (Figure 8.13 D) recovered in Harappan Period levels at Nagwada in northern Gujarat. Importantly, this site is located just east of the Little Rann of Kutch around 60 km from the agate source at Mardak Bet.

Finally, Jean-François and Catherine Jarrige (Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet Paris), graciously provided a set of eight agate fragments (Figure 8.13 D) from the site of Mehrgarh. Seven are plain or banded chalcedony and one is carnelian. All are surface finds from the site’s MR2 area, which would date them to Mehrgarh Period III (ca. 4800-3500 BC). The Jarriges also supplied seven broken carnelian beads (Figure 8.13 E) from their excavations at nearby Nausharo. Three come from levels (Period 1C and 1C/1D) around the site’s Early Harappan-to-Harappan Phase transition (Jarrige 1993) while four are from Harappan Phase levels (Period III – ca. Period 3B at Harappa). The Mehrgarh and Nausharo artifacts are of particular interest because of those sites’ location the foot of the Bolan Pass – a major route into the highlands of Balochistan and beyond to the Helmand Basin. People living there would have been well-placed to acquire agate from sources to the west of the Indus Valley.

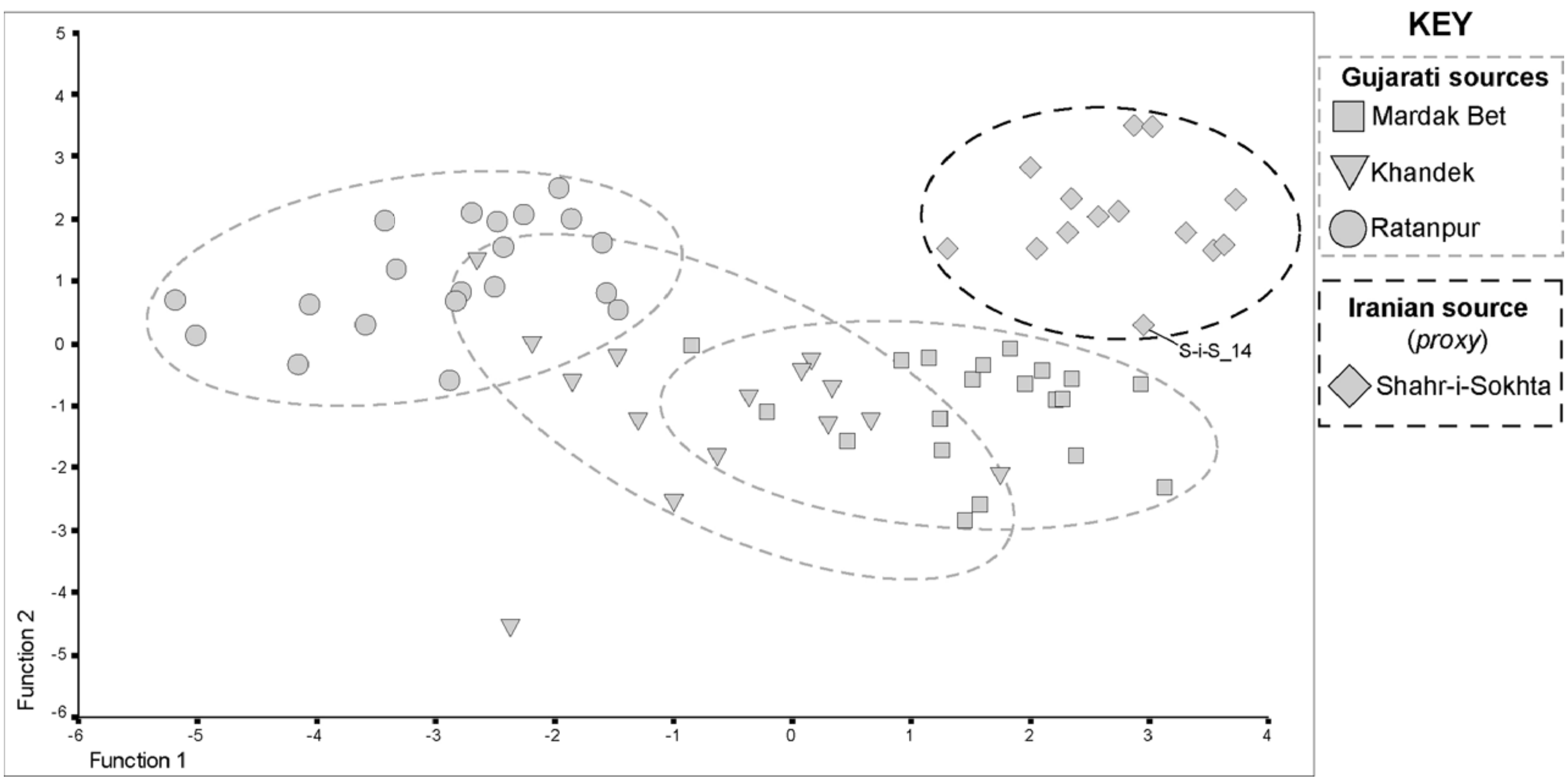
Analysis and comparison

The sets of agate artifacts and geologic source samples introduced above were subjected to instrumental neutron activation analysis (INAA) following sample preparation and irradiation procedures outlined in Chapter 2. Out of the data that were returned, ten elements (Al, Co, Cr, Eu, Fe, La, Na, Sb, Sc and V) free of missing values were selected for use in comparisons of the two sets using canonical discriminant analysis (CDA). The measured concentrations of those elements in the source samples and artifacts are listed in the following appendices: GRTP = Appendix 8.1; GMB = Appendix 8.2; GKK = Appendix 8.3; S-i-S = Appendix 8.4; Harappa artifacts = Appendix 8.5; Mehrgarh and Nausharo artifacts = Appendix 8.6; Mohenjo-daro, Chanhu-daro and Nagwada = Appendix 8.7. In Appendix 8.9, the standardized (canonical) discriminant function coefficients for each of the figures in this chapter generated using CDA (8.14 through 8.17) are listed.

First, the GMB, GKK, GRTP source and S-i-S proxy source samples were compared to one another as four sets of grouped cases (Figure 8.14). Good separation between the source-groups resulted. Exactly 85.1% of leave-one-out cross-validated grouped geologic cases were classified correctly. Most of the misclassification (overlap) that occurred was among the three Gujarati agate sources. Only one sample from S-i-S (noted on Figure 8.14) was misclassified as belonging to a Gujarati source (Mardak Bet) when it was cross-validated. That particular fragment – S-i-S_14 (Figure 8.10 D, *bottom row, fourth from the left*), is a piece of milky, semi-translucent chalcedony that is unlike the other samples (both the variegated agate-carnelians and the bluish-chalcedonies). Overall, however, it can be said that the Iranian agates are quite distinct from the Gujarati sources.

Figure 8.14: CDA comparison of Gujarati and Iranian (proxy) agate sources

Discriminant Functions generated using the elements Al, Co, Cr, Eu, Fe, La, Na, Sb, Sc, and V

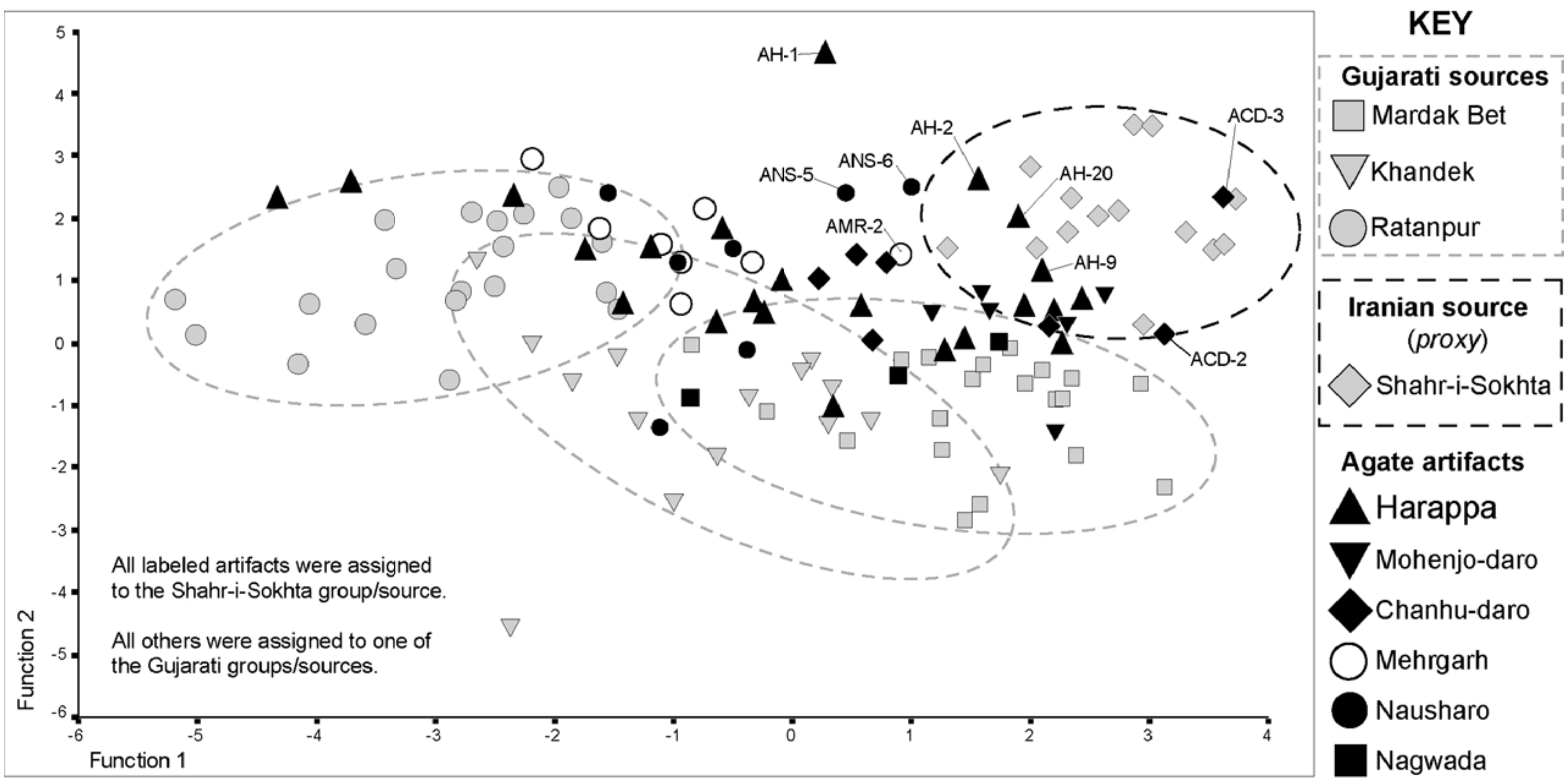


Next, the agate artifacts from Harappa and the five other sites were compared to the grouped geologic sources and plotted as ungrouped cases in relation to them (Figure 8.15). The first predicted group memberships (PGMs) for all of the artifacts are listed in the column labeled *Figure 8.15* in Appendix 8.8. In total, nine of the 56 artifacts had a first PGM in the S-i-S proxy source-group. Each of those nine are labeled on Figure 8.15. Four of them were from Harappa (AH-1, 2, 9 and 20), two were from Chanhu-daro (ACD-3 and 4), two were from Nausharo (ANS-5 and 6) and one was from Mehrgarh (AMR-2). The remaining 47 agate artifacts were assigned a first PGM in one of the three sources in Gujarat. Twenty-six of those had a PGM in the Mardak Bet source-group and 16 had a PGM in the Khandek source-group. Only five agate artifacts had a PGM in the Ratanpur source-group. Two of these were from Harappa (AH-14 and 22) and one each was from Nagwada (ANG-1), Mehrgarh (AMR-8) and Nausharo (ANS-4).

The results of the initial CDA indicate that majority of the artifacts analyzed from Harappa and the other sites are geochemically more analogous to agate from sources in Gujarat than they are to agate artifacts from Shahr-i-Sokhta, which are presumably from a source(s) in the general vicinity of that site in eastern Iran. Furthermore, the majority of those artifacts predicted to belong to one of the Gujarati sources are more closely related to agate samples from Mardak Bet and Khandek in northern Gujarat than they are to samples from the Ratanpur area in the southeastern part of that state. However, rather than making interpretations based upon these initial results, two additional CDAs were conducted in an effort to 1) achieve better discrimination between the Gujarati sources and the S-i-S group and 2) achieve better discrimination between the three Gujarati sources themselves.

Figure 8.15: CDA comparison of agate artifacts to Gujarati and Iranian agate sources

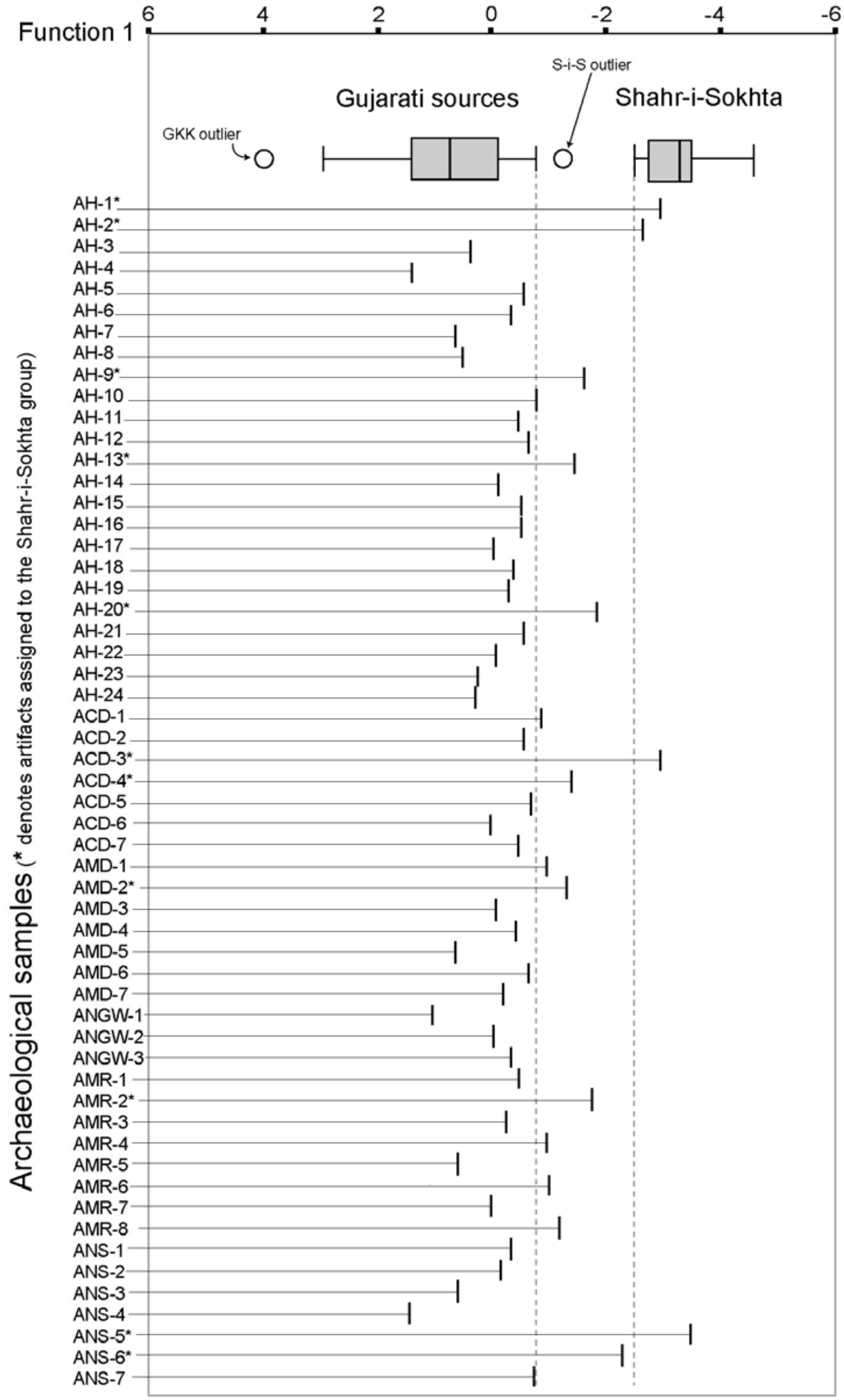
Discriminant Functions generated using the elements Al, Co, Cr, Eu, Fe, La, Na, Sb, Sc, and V



In order to achieve better statistical separation between agate samples from Gujarat and agate artifacts (presumably) from Iran, the cases that make up GMB, GKK and GRTP were combined into a single group that was designated "Gujarati sources." This new source-group was then compared to the S-i-S proxy source-group using CDA. Because only one discrimant score (function) is generated when two groups of cases are compared to one another, it is not possible to make a bivariate plot of the results. An excellent way to display univariate data of this kind is by using a *box plot* (sometimes called a box-and-whisker diagram). For the box plots shown on the next page (Figure 8.16), the two sets of grouped cases ("Gujarati sources" and S-i-S) and the ungrouped cases (agate artifacts from Harappa and the other sites) were plotted on a horizontal axis based on their first (and in this case only) discriminant scores. The distribution of the case data making up each group-source is divided into quartiles with the gray boxed areas depicting the second quartile, which encompasses the middle 50% of the cases. The range demarcated by the "whiskers" that extend from the left and right of the box depict the lower and upper 25% of the case data (the first and third quartiles respectively). The median of the grouped cases is depicted as a line dividing the second quartile box and individual cases that are outliers of the main group of cases are plotted apart as small circles. For more detailed information regarding the generation and utility of box plots see Shennan (1997: 45-46) or Benjamini (1988).

Excellent (although still not perfect) separation between the Gujarati sources group and the S-i-S group was achieved. Precisely 95.9% of leave-one-out cross-validated grouped cases were classified correctly. Proxy source sample S-i-S_14 (the labeled outlier of the S-i-S box plot in Figure 8.16) was again misclassified as belonging to a Gujarati

Figure 8.16: Gujarati agate sources compared as one group to the Shahr-i-Sokhta agates. Box plots generated and artifact points plotted using the CDA first discriminant function.



source. Two samples from the Gujarati source-group (GMB-13 and GKK-14) were misclassified as belonging to the S-i-S group. By and large, however, the two source-groups are very distinct from one another as is evident from their box plots on Figure 8.16. Dashed lines were drawn to indicate the upper limit of the Gujarati sources' third quartile and the lower limit of the S-i-S group's first quartile (which does not include the outlier). The artifacts from Harappa and the five other sites are plotted below the box plots of the two source-groups using small vertical bars. A thin line connects each bar to a label on the left side of the plot that indicates the number of the artifact it represents. The PGMs for all of the artifacts are listed in the column labeled *Figure 8.16* in Appendix 8.8. In this CDA, the PGM of eleven artifacts was in the S-i-S group. Each of these is identified on the figure by an asterisk next to its label. They include the exact same nine predicted to belong to the S-i-S group in the previous CDA (Figure 8.15) plus AMD-2 and AH-13.

The results of this CDA once again indicate that the large majority of the artifacts analyzed are more closely related to agate samples from sources in Gujarat than they are to artifacts/proxy source samples from Shahr-i-Sokhta. Note, however, that a number those that were assigned to the Gujarati source-group (AMR-4, 6 and 8, AMD-1 and ACD-1) lie above the upper limit of its third quartile while many of those assigned to S-i-S (AH-9, 13 and 20, ACD-4, AMD-2, AMR-2, ANS-6) plot below the lower limit of its first quartile. Such artifacts could genuinely be outliers of the source-group to which they were assigned. Alternately, they could be misclassified outliers of the opposite source-group. They could (and so could any other artifact in the set regardless of where it plotted) also be from a source not analyzed and simply assigned to the one in the set they more closely resembled.

For the final CDA, the three agate sources in Gujarat (GMB, GKK and GRTP) were compared to one another alone, without the S-i-S proxy source-group (Figure 8.17 A). Although good separation between the three was achieved, it was only slightly better than that for the original CDA (Figure 8.15). Exactly 86.7% of leave-one-out cross-validated grouped cases were classified correctly this time whereas 85.1% were classified correctly when the S-i-S source-group was included in the analysis. This indicates that nearly all of the overlap (misclassification of grouped cases) in the dataset is among Gujarati sources rather than between them and the Iranian artifact/proxy source samples. In this instance, the misclassifications were among the GMB samples (one was predicted to belong to GRTP) and the GRTP samples (one was predicted to belong to GMB and three to GKK).

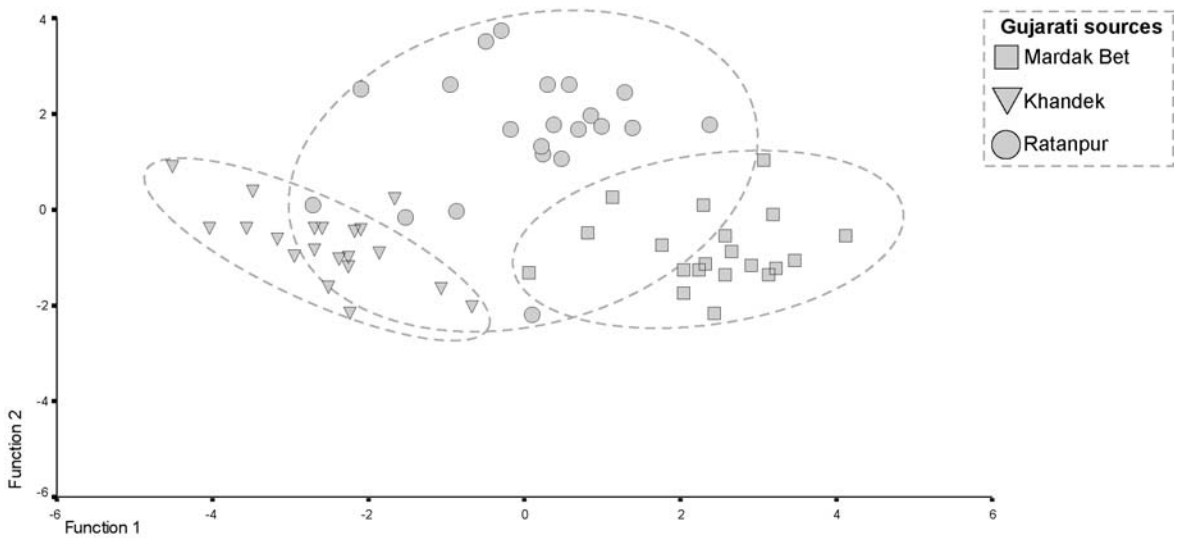
On Figure 8.17 B, the 45 artifacts that had *not* been predicted to belong to the S-i-S proxy source-group in one of the previous CDAs are plotted as ungrouped cases in relation to the three Gujarati source-groups. The PGMs for each of those are listed in the column that is labeled *Figure 8.17* in Appendix 8.8. In this CDA, 27 artifacts were predicted to belong to GMB, 14 to GKK and four to GRTP. For the most part, these PGM assignments are unchanged from the first CDA (compare them to column labeled *Figure 8.15* in Appendix 8.8). Two artifacts that had been assigned to GMB now had a PGM in GKK and one that had been assigned to GRTP was now predicted to belong in GMB.

The results of this CDA serve to confirm what was evident in the initial one – that the majority of those agate artifacts assigned to a Gujarati source more closely resemble samples collected from Mardak Bet and Khandek than they do samples from Ratanpur. Before commencing with the interpretation of all the results in the next section, it should be

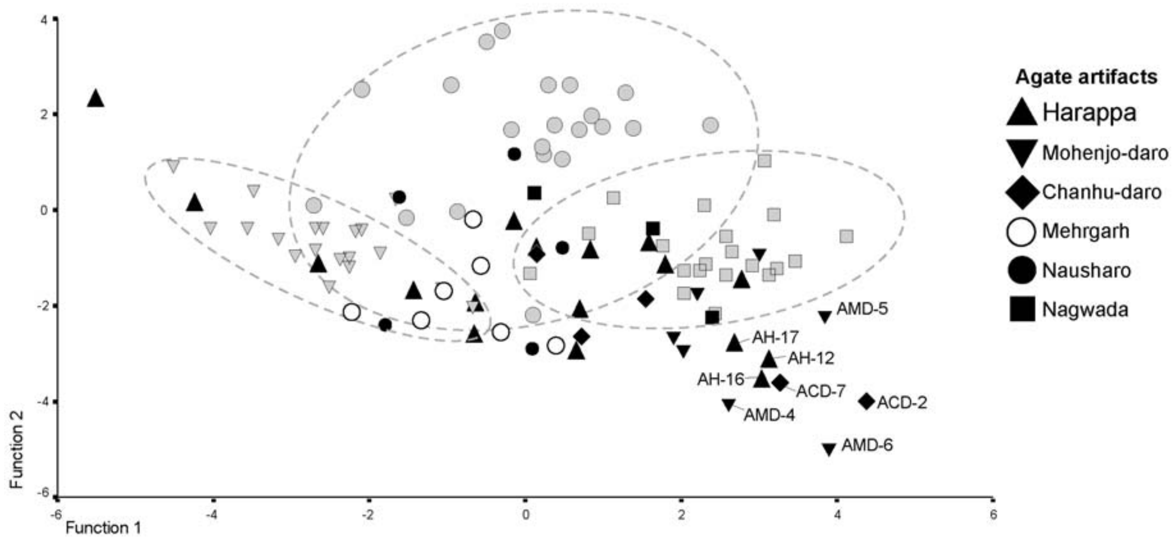
Figure 8.17: CDA comparison of select agate artifacts to three agate sources in Gujarat

Discriminant Functions generated using the elements Al, Co, Cr, Eu, Fe, La, Na, Sb, Sc, and V

A. CDA comparison of the three agate sources alone



B. **S**elect agate artifacts (those not previously assigned to the S-i-S group) plotted as ungrouped cases in relation to the three agate sources.



noted that there are a number of artifacts that, while assigned to Gujarati sources in the first two CDAs, now plot apart from the three source-groups in Figure 8.17 B suggesting that they are somewhat distinct from them. Dashed ellipses (these and the ones on the other figures in this chapter are visual guides and not any form of confidence interval) have been drawn around the source groups and a few of the more distant outliers have been labeled. These artifacts might merely be outliers of the sources to which they are assigned. However, they could be from a different source in Gujarat or even from a source outside of that region. It is for this reason that caution is advised. The geologic data set that the artifacts are being compared is not necessarily representative of all of the potential sources to which Indus Tradition might have had access. Any interpretation of the results must recognize this element of uncertainty and include the appropriate qualifications.

Interpretation (and qualification) of the results

If the results of this study are taken at face value – i.e., without questioning any of the PGMs made during the CDAs presented above, then the following statements can be made: It appears that Indus Tradition peoples at the sites of Harappa, Mohenjo-daro, Chanhu-daro, Nausharo, Mehrgarh and Nagwada acquired the majority of their agate from the Gujarat region. Most of it came from sources located in the northern part of that state rather than from the Ratanpur area, as is often assumed. There are some indications that Early Harappans and/or Harappans at all of the sites examined (except for Nagwada) may have also utilized some agate from sources other than the three in Gujarat that were analyzed. Some of those sources were probably located elsewhere in Gujarat while others may have been in regions to the west of the Indus Valley. Although this interpretation is,

more or less, the same as that presented in the provisional conclusion for this chapter, there are multiple aspects of it that require qualification.

Artifacts from Harappa

First of all, consider the five agate artifacts from Harappa that were predicted in the first and/or second CDAs to belong to the S-i-S proxy source-group. Included among them are the two large agate-chalcedony nodule fragments (AH-1 and 2) pictured in Figure 8.12. These were the only two that actually plotted among the spread of discriminant scores that make up the box plot for S-i-S on Figure 8.16. Assuming that the Shahr-i-Sokhta artifacts did not come from a source in Gujarat (or from a geochemically related source elsewhere in the Deccan Traps) then it is reasonable to assume that the two nodules likewise did not come from that region. I am, however, reluctant to firmly declare that they are from a source in eastern Iran. They are obviously very different in size and appearance from those Tosi described in the vicinity of Shahr-i-Sokhta. They might instead have come from occurrences in southern Afghanistan or western Balochistan. Or they might be from a source in an altogether different region. Still, geochemically, the nodules do resemble the S-i-S artifacts far more than they do the geologic samples from sources in Gujarat. Therefore, it is provisionally concluded that Harappans likely acquired them from an agate occurrence(s) to the west of the Indus Valley, perhaps one in the Helmand Basin region.

The remaining three artifacts from Harappa (AH-9, 13 and 20) that were predicted to belong to the S-i-S source-group plotted in the gap between that group's first quartile and the Gujarati sources group's third quartile. For this reason, I am even more reluctant to than I was with AH-1 and 2 to accept their PGMs; that is, at least not without first making a

few qualifying statements. These artifacts could well be outliers of the Gujarat Mardak Bet source that just happened to plot nearer to the centroid of the S-i-S source-group. AH-13 was actually assigned to GMB in the initial CDA (see Appendix 8.8). It is also possible that the three are from unsampled agate deposits in Gujarat (such as those in central Kutch or the ones in the Kapadvanj area) that happen to have trace element characteristics slightly more like those of the source(s) from which the Shahr-i-Sokhta artifacts were acquired (wherever that might be). Furthermore, it should be noted that AH-20 is a fragment of a carnelian long bead. The large-sized iron-impregnated nodules required to make those beads are not, at least to my knowledge, found in regions outside of Gujarat or Central/Peninsular India. There might, of course, be sources of such nodules to the west or north of the Indus Valley that have not been reported or described. For that matter, there also may be agate sources in those regions that have trace element characteristics similar to the ones in the Deccan Traps – the Laki Formation trap of Sindh Kohistan is a strong candidate for being one of these. However, until those other potential sources are better described and analyzed it is impossible to do more speculate. Based on limited geologic dataset that was available for comparison, the best that can be said at present is that AH-9, 13 and 20 *may* have been acquired from a source to the west of the Indus Valley.

With regard to the 19 agate artifacts from Harappa that were consistently assigned to one of the Gujarati sources, it can be stated that most likely came from a deposit in the northern part of that state (a few possible exceptions – the outliers labeled on Figure 8.17B, are discussed below). When the three Gujarati sources analyzed were compared only to one another (Figure 8.17), just a single artifact (long bead fragment AH-22) was assigned

to the Ratanpur source. Of course, the cross validation success rate for that CDA was 86.7%, which means that some of the artifacts assigned to GMB and GKK might have actually be misassigned outliers of GRTP. On the other hand, AH-22 could just as easily be a misassigned outlier of GMB, which was its second PGM. I favor the latter possibility given the fact that 11 of the 19 agate artifacts were predicted to belong to the GMB source.

One chalcedony fragment (AH-12) and two broken carnelian long beads (AH-16 and 17) from Harappa are among the handful of agate artifacts (labeled on Figure 8.17 B) that in the third CDA plotted markedly apart from the three Gujarat source-groups. It is possible that some or all of these distinct artifacts are outliers of GMB – the source to which all were assigned. Characterization of additional geologic samples could expand the spread of cases making up that source-group enough to encompass them. On the other hand, the distinctiveness of the artifacts may be an indication that they are from a different source(s). Although that other source(s) could be outside of Gujarat, in the case of the long beads at least, I would argue (for the reason discussed on the preceding page) that it is probably located somewhere within that state. However, until other potential agate sources in Gujarat are sampled and analyzed, the current PGMs of these distinct artifacts will stand.

Artifacts from the five other Indus Tradition sites

The PGMs generated for the artifacts from Nagwada are fairly straightforward. It appears that the Harappans of that site were, not surprisingly, acquiring agate from sources in Gujarat. Two fragments were assigned to the relatively nearby occurrence at Mardak Bet while one was predicted to come from the Ratanpur source. With regard to artifacts analyzed from the four other Indus Tradition sites, a few qualifying remarks are required.

All but one of the Mohenjo-daro artifacts analyzed were predicted to belong to the GMB source. The single fragment (MD-2) from that site that was assigned to the S-i-S group in the second CDA (Figure 8.16) is likely a misassigned GMB outlier. Most of the Chanhu-daro artifacts were also predicted to belong to GMB. Of the two from that site that were assigned to the S-i-S proxy source-group, one (ACD-4) is perhaps a misassigned GMB outlier. The other (ACD-3) is distinct enough (see it plotted on figures 8.15 and 8.16) to suggest that it is probably from a source outside of Gujarat. As was the case with the two large chalcedony nodules from Harappa discussed at the beginning of this section, that source could be in the Helmand Basin region. On the other hand, agate occurs just 40 km west of Chanhu-daro in the trap rock of Sindh Kohistan's Laki Range. If raw material of even marginal quality exists at that location (this is by no means certain) then there is a strong possibility that some of it ended up in the workshops of Chanhu-daro and, for that matter, of Mohenjo-daro and Harappa too. The artifacts from all three of those sites that plotted distinctly apart from the Gujarati sources on Figure 8.17B might conceivably have come from the Laki Trap. That formation is reportedly a western outlier of the Deccan Traps and so the agate from it might geochemically resemble agate from Gujarat. Or it might not. It is impossible know until samples from that potential source are analyzed.

Most agate artifacts from Mehrgarh and Nausharo were predicted to belong to an occurrence in Gujarat. However, unlike like those from Mohenjo-daro and Chanhu-daro, few were assigned to the Mardak Bet source. ANS-3 was the sole artifact that consistently had a PGM of GMB. AMR-5 and ANS-2 were assigned to that source only in the third CDA. In the first, they had PGMs of GKK and so may be outliers of that source that were

subsequently misclassified. If that was the case, then six of the eight artifacts from Mehrgarh and three of the seven from Nausharo may be from GKK. One artifact at each site was assigned to GRTP while one agate fragment from Mehrgarh and two beads from Nausharo were consistently predicted to belong to the S-i-S proxy source-group.

It is curious how the majority of the agate artifacts at Mehrgarh were predicted to belong to the GKK source while most of those at Mohenjo-daro and Chanhu-daro were assigned to GMB. Both of those occurrences are located within 40 km of each other in northern Gujarat. Why would peoples at those distant settlements in Sindh and Balochistan have almost exclusively utilized raw material from one source over the other? It is quite possible that what appears to be an emphasis on one source is actually the product of a very limited sample. The analysis of a larger number of artifacts from different phases and parts of the sites in question might reveal more heterogeneous patterns of agate source utilization, like that seen at Harappa. Another reason might have to do with the fact that the Mehrgarh artifacts are from an earlier period (ca. 4800-3500 BC) than those of the other Indus Tradition sites examined in this study. Perhaps material from GMB was not being exploited and/or exported during that earlier period. Later, during the Harappan Period (when GMB agate was evidently being used at sites across the Indus Valley), one or two agate artifacts that may be from that source do appear at the nearby site of Nausharo. A final possibility that must be considered is that some or all of the artifacts from Mehrgarh (and possibly Nausharo too) assigned to GKK might not actually be from Gujarat.

Mehrgarh and Nausharo, located as they are at the foot of the Bolan Pass, were the two sites at which I had most expected to see evidence for the utilization of agate from

occurrences to the west of the Indus Valley. And, in fact, there are some artifacts (AMR-2, ANS-6 and, in particular, ANS-5) at both that might be from the Helmand Basin region. That many more were predicted to be from sources in Gujarat was not wholly unexpected. After all, residents of Mehrgarh had been acquiring raw materials (lapis lazuli, turquoise and marine shell) from distant regions since that settlement's earliest period (Jarrige 1991b: 41) and Nausharo was a thriving Indus Civilization town (Jarrige 2000). I have, however, doubts about the correctness of the provenience determinations made for many of the artifacts from the former site. It is not only because their PGMs stand in contrast to those of artifacts from Mohenjo-daro and Chanhu-daro (discussed above). It is also because the quality of several artifacts in the group assigned to GKK – in particular the two tiny chalcedony geode fragments (AMR-6 and 7, pictured on 8.13 E), is rather mediocre. Agate of this type occurs at Khandek but it is hard to fathom why someone would have seen fit to transport it approximately 700 km to Mehrgarh when there was much better raw material available at that source and at others in northern Gujarat. It seems more likely that many of the artifacts in question derived from an occurrence nearer to the site, perhaps the one Masson mentioned (1844: 463) "east of Kalat" in central Balochistan or another one like it. There are no published descriptions of agate from that source and until some is collected and analyzed we have no way of knowing if it is geochemically similar to that from GKK. However, if does turn out to be similar then that has important implications. If some or all of the GKK-assigned artifacts from Mehrgarh are actually from an occurrence to the west of the Indus Valley then those at Harappa assigned to that source could be as well. This possibility further underscores the need to regard the results of this study as provisional.

Now that all necessary qualifying remarks have been stated, the conclusions of this study can be presented. The three lines of inquiry outlined in Chapter 1 are not addressed here as the artifacts analyzed from Harappa are not sufficiently representative, either spatially or temporally, to permit this. The results are instead incorporated into the final overview of Harappan rock and mineral acquisition networks in Chapter 13.

Chapter conclusion

The results of this study bode well for future research of this kind. Using INAA and CDA, it was possible to differentiate samples from three agate deposits in Gujarat reasonably well. However, a superb degree of discrimination was achieved when those deposits were compared to a set of artifacts presumably from sources in eastern Iran. This indicates that it is possible, at the very least, to assign a regional provenience to agate artifacts. The results of a recent follow-up study (Carter et al. *in preparation*) lend further support to this conclusion. Samples from two deposits in Gujarat – the group of Iranian artifacts and a newly sampled source in Thailand (Ban Khao Mogun) – were analyzed at the Missouri University Research Reactor. An excellent 95.1% cross validation success rate was achieved. Most of what little misclassification there was occurred the among the Gujarati sources rather than between them and the other regional source or proxy-source samples. There is then very good reason to expect that when the geologic dataset is further enlarged to include agate from deposits in Sindh, Balochistan, Afghanistan, Arabia, Tibet and Central Asia it will be possible to differentiate them and assign a regional provenience to artifacts. In the meantime, the results of the present study permit the following *provisional* conclusions to be made regarding Indus Tradition agate acquisition networks:

The majority of the agate artifacts from Harappa and the five other Indus Tradition sites examined in this chapter appear to have come from sources in Gujarat. Residents of Harappa were acquiring material from that region by at least the Kot Diji Phase. Although this conclusion is based solely on the analysis of a single carnelian bead fragment (AH-24) from Period 2 levels, that particular artifact is one of the more analogous to geologic samples from the Mardak Bet occurrence (it was consistently assigned to that source and is not among distinct outliers on 8.17B). Gujarat was evidently the primary agate source area for residents of Harappa during the latter half of the Harappa Phase. All but one of the ten artifacts from the site that are securely attributable to periods 3B and 3C were predicted to belong to a deposit in that region. Significantly, most of the Gujarati agate used at Harappa and the other sites appears to have come from sources in the Kutch region rather than from, as is widely assumed, the Ratanpur area deposits in the southeastern part of the state.

There are indications that Indus Tradition peoples sometimes utilized agate from regions outside of Gujarat. Four artifacts from Harappa (including a Period 3B bead fragment) as well as a few from Mehrgarh, Nausharo and Chanhu-daro are geochemically more analogous to artifacts from Shahr-i-Sokhta, which suggests that they may have come from the same sources (presumably in the Helmand region) used by residents of that site. Also, a few of the Gujarat provenience assignments for artifacts from Harappa and the other sites are, in my judgment, tenuous (especially certain ones from Mehrgarh). It is possible that those artifacts may come from a source(s) to the west of the Indus Valley.

In the next chapter, I examine the acquisition of vesuvianite-grossular garnet – a translucent green-colored rock that has in the past been misidentified as “jade.”

Chapter 9

Vesuvianite-grossular acquisition networks

Chapter 9 – Vesuvianite-grossular acquisition networks

Chapter Introduction – Harappan "Jade"

In this chapter, I examine a distinctive translucent green to yellowish-green rock that has been recovered at Harappa in the form of beads, amulets and manufacturing debris (Figure 9.1 A). The Italian researchers Vidale and Bianchetti (1997) analyzed three of the debris fragments using X-ray diffraction (XRD) and determined them to be composed of a mixture of the minerals vesuvianite and grossular garnet (called here "vesuvianite-grossular"). They went on to suggest that translucent green beads from Mohenjo-daro (Figure 9.1 B *top*), which were previously identified as "a peculiar form of jade" (Coulson 1931: 542), may actually be composed of this variety of stone. Ernest Mackay (1938: 498) regarded the supposed presence of jade at that city as evidence of the Indus Civilization's contacts with distant jade source areas in either Central Asia (Xinjiang) or Burma (modern Myanmar). Vidale and Bianchetti's identification of vesuvianite-grossular – a rock that greatly resembles jade and has several of the same mineralogical characteristics, cast doubt on that interpretation. More recently, the Italian team hypothesized (Vidale and Bianchetti 1999) that this stone may have even been a long-distance export from the Indus Civilization to consumers in Mesopotamia region.

I begin this chapter with an overview of the mineralogy of vesuvianite-grossular followed by an account of the effort to identify and characterize artifacts composed of it at Harappa. After that, the possibility that past researchers misidentified this rock as the mineral jadeite is explored. Next, I review the potential sources of this stone in South Asia and present the results of an INAA study in which samples from three of those sources

were compared with artifacts from Harappa and Mohenjo-daro. I then consider Vidale and Bianchetti's hypothesis that vesuvianite-grossular may have been an export from the Indus region to Mesopotamia. In the concluding section, I explore the spatial and temporal distribution of vesuvianite-grossular at Harappa and discuss what appears to be its close association with "Ernestite," which is only material in the assemblage from which drills capable of perforating it could have been made. All sites, geologic sources and geographic regions mentioned in this chapter are identified on figures 9.5 and 9.6.

Figure 9.1: Vesuvianite-grossular garnet artifacts …

A … from Harappa

B. … from Mohenjo-daro



The mineralogy of vesuvianite-grossular

The translucent green-colored stone that is the subject of this chapter is a rock composed primarily of two distinct minerals: vesuvianite and grossular garnet. In order to best understand the particular nature of this material and how it was used at Harappa, it is useful to be aware of each mineral's individual properties and variability.

Vesuvianite is a rock-forming silicate mineral first described in blocks of metamorphosed limestone on the slopes of Mt. Vesuvius (Pough 1988: 281). Its exact chemistry, structure and even official designation (which has alternated between vesuvianite and *idocrase* several times in recent decades) are subject to continued debate (Allen 1985: 2). Several chemical formulae have been proposed over the years (Groat et al. 1992: Table 2). The most recent edition of *An Introduction to the Rock-Forming Minerals* (Deer et al. 1992) lists it as Ca_{19} $(Al, Fe)_{10}$ $(Mg, Fe)_3$ $[Si_2O_7]_4$ $[SiO_4]_{10}$ $(O,OH,F)_{10}$. Published specific gravity (SG) values of pure vesuvianite range from 3.32 to 3.5 and its hardness is reported to fall between 6 and 7 on Mohs' scale (Deer et al. 1992: 47; Pough 1988: 280; Read 1979: 375). Vesuvianite is transparent to translucent and its color can range from yellow, green, to brown, with rare occurrences of red or blue (Deer et al. 1992: 47). The mineral most commonly occurs in areas resulting from the contact metamorphism of calc-silicate rocks (skarns), the metasomatic alteration of ultramafic rocks that results in rodingites (rodingitization – discussed on the next page) or, more rarely, in metasomatically altered alkali syenites (Allen 1985: 147-155). Pure vesuvianite is not a commonly used gemstone today, although it is known to occur both as "gemmy" pyramidal crystals and in a massive form that sometimes resembles jade (Pough 1988: 280-81).

Grossular is a member of the garnet group and has a chemical formula of $Ca_3Al_2Si_3O_{12}$ (Deer et al. 1992: 31). Like vesuvianite, it is a variable mineral. Published SG values range between 3.57 to 3.73 and its hardness may run from 6 up to 7.5 (Manson and Stockton 1982: Table 1). Pure grossular is colorless (ibid.: 207) but gem varieties have two distinct color trends: a yellow to orange to red-brown range called "hessonites" and a light yellow-green to dark green range called "tsavorites" (ibid.; Hansen 1986: xii). The mineral is transparent to translucent and occurs both as a crystal and in a massive form. Massive green grossulars from Africa and Pakistan are used a jade simulants by jewellers in both countries (Qaiser et al. 1970: 735; Rothstein 1983: 611-13). Also like vesuvianite, grossular garnet forms in both regionally metamorphosed calc-silicate rocks and ultramafic rocks (most notably ophiolite sequences) that have undergone a metasomatic conversion sometimes called *rodingization* (Deer et al. 1992: 44; Hansen1986: xiii).

Although of different mineral families, the crystal structures of vesuvianite and grossular garnet are very similar (Groat et al. 1992: 22), with certain aspects being nearly identical in both (Deer et al. 1992: 47). The *c* axis of tetragonal vesuvianite is approximately equal to the length of the cubic edge of grossular (Allen 1985: 10). Thus, vesuvianite and grossular garnet, which form under similar conditions, frequently occur together. The term "californite" is informally used to describe a massive rock composed of vesuvianite and grossular garnet that may resemble jade (Rothstein 1983: 606) and which has a density of between 3.25 and 3.35 (Webster 1975: 232). It appears to be this co-occurring variety (which can grade in a single deposit from predominantly grossular to predominantly vesuvianite – Anderson 1966: 119) that is found at Harappa.

Characterization and identification of vesuvianite-grossular at Harappa

There are several varieties of rocks and minerals such as serpentine, nephrite "jade," jadeite "jade," periodote and green quartz, which vesuvianite-grossular may be mistaken for (or vice versa). In fact, the three fragments from Harappa that Vidale and Bianchetti (1997) identified were originally classified as serpentine, as were most translucent green-colored varieties of stone encountered during HARP operations up to that point. For this reason, it was considered essential to reexamine all artifacts of this description recovered at the site. This was done in two stages. For the first, a set of 26 translucent green-colored debris fragments was assembled for an initial round of mineralogical characterization involving XRD analysis and specific gravity (SG) testing. All samples were surface finds chosen to represent the full range of hues and material qualities (based on degree of internal fracturing) present in the sub-assemblage. XRD results and specific gravity determinations on these 26 have already been listed in Appendix 4.1. Seven of the samples underwent supplementary characterization using electron microprobe analysis (EMPA) – the details of which are provided in Appendix 9.1. For comparative purposes, five samples from two vesuvianite-grossular sources in Pakistan (described later in the chapter) were also analyzed (using XRD and EMPA) with the group. Informed by the results of these initial studies, the second stage of reexamination involved SG testing of all green-colored stone artifacts (translucent or otherwise) recovered at Harappa weighing 0.5 grams or more.

XRD analysis of the initial group of 26 archaeological samples revealed that, in every case but one (H94/4999-213, which turned out to be a flake of green-colored quartz), the fragments were composed of either vesuvianite or grossular, or some mixture of both.

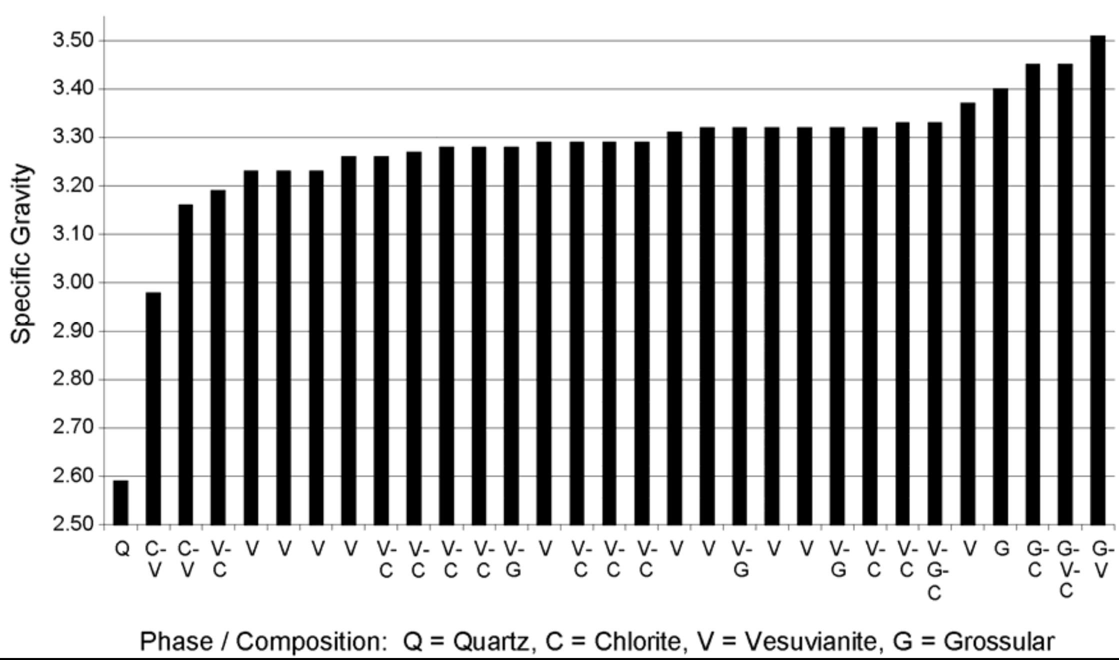
Although it is not impossible that three distinct rocks and minerals (vesuvianite, grossular garnet and co-occurring vesuvianite-grossular) are represented among the samples, I consider it more likely that they all are fragments of the type of massive, heterogeneous vesuvianite-grossular rock sometimes called "californite." Chlorite (variety clinochlore) – a common constituent and/or weathering product of ferromagnesium rocks and minerals (Deer et al. 1992: 340), was also detected (either by XRD or EMPA) in approximately half of the samples analyzed and was the primary component in two of them.

To best conceptualize the range of compositional variability in the vesuvianite-grossular sub-assemblage at Harappa, recall Appendix 4.2 F – a composite of four of the XRD scans of debris fragments. The top scan (H2000/9999-91) shows a fragment that appears to be composed entirely of grossular garnet. However, EMPA scans of this sample showed that vesuvianite and chlorite, in amounts undetectable by XRD, was also present in the stone. Below this is a sample (H94/5106-8) that contains a secondary phase of vesuvianite, although still being primarily (as determined by peak intensity) composed of grossular. The third scan from the top (H90/3220-4) shows a material that is primarily vesuvianite with a very minor phase of chlorite. The bottom scan (H94/5310-36) shows a fragment composed primarily of chlorite with a secondary phase of vesuvianite. Sample H94/5310-36, which is a highly fractured, cloudy pale-green flake, perhaps represents the unusable weathered exterior that was discarded during the processing of a vesuvianite-grossular blocklet. Most finished and unfinished vesuvianite-grossular ornaments recovered at Harappa are composed of clearer stone that contains substantially fewer fractures. The five geologic samples that were examined along with the initial group

(Appendix 9.1) exhibit the same mineralogical variability and are more or less identical in appearance to vesuvianite-grossular artifacts from Harappa.

Specific gravity determinations were made on all 26 archaeological fragments (these are listed with the samples in Appendix 4.1) and the five geologic samples (listed with those samples in Appendix 9.1). Although the overall density range of vesuvianite-grossular appears extremely wide (from just under SG 3.0 to over 3.5), it must be remembered that it is a heterogeneous rock, rather than a pure mineral, that has been tested. When density values are considered together with the primary and secondary mineral phases of each sample an important trend is revealed (Figure 9.2). With the exception of the single fragment that turned out to be green quartz, the samples with the lowest SG are those in which chlorite is the primary component. The bulk of the samples

Figure 9.2: Specific gravity and composition of 31 translucent green-stones. (*26 debris fragments from Harappa and five geologic samples*)



are composed mainly of vesuvianite with occasional secondary components of grossular and/or chlorite. The samples having the highest SG values are those with grossular as their primary component. I show below that this trend from low density chlorite-dominated stone to high-density grossular-dominated stone is, to a certain degree, mirrored in the discard patterns of vesuvianite-grossular artifacts.

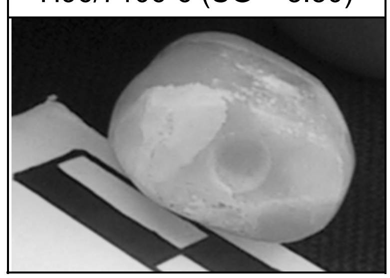
With an understanding of vesuvianite-grossular variability informed by the results of the initial XRD, EMPA and SG studies, all green-colored stone beads, pendants and ornament manufacturing debris fragments recovered at Harappa since 1986, as well as those from previous excavations on display in the Harappa Museum and its reserve collection, were re-examined during the 2003 field season. Many rock and mineral varieties, such as tourmaline, amazonite (microcline), malachite, turquoise, fluorite and green varieties of steatite, were easily distinguishable from vesuvianite-grossular based on their hardness, texture and/or crystal habit. Most green-colored artifacts composed of quartz (bloodstone, moss agate, green jasper) or opaque varieties of serpentine were likewise distinguished without difficulty. If there was any uncertainty at all, the low density of quartz (2.6) and serpentine (2.5 to 2.7) as compared to vesuvianite-grossular (≈ 3.0 to over 3.5) made definitive differentiation possible as the SG of most artifacts was tested. Density determinations could not be made on artifacts under 0.5 grams due to the inaccuracy of the SG balance below that weight. Thus, fragments of "micro-debitage" had to be identified based solely on their macroscopic properties. Ultimately, 543 artifacts from Harappa (including Vidale and Bianchetti's 3 samples and the 25 fragments characterized using XRD/EMPA) were classified (or re-classified) as vesuvianite-grossular.

Interestingly, when vesuvianite-grossular manufacturing debris, unfinished beads and finished ornaments are considered separately, their average densities are somewhat different (Figure 9.3). The mean SG of the 161 weighed fragments of vesuvianite-grossular ornament manufacturing debris is 3.28. The mean of the 11 unfinished beads is 3.35 and the mean of the 10 finished ornaments is 3.31. Although the density discrepancies might be due to small numbers of finished and unfinished items considered, it may also be indicative of a pattern relating to the use and discard of this type of stone. The lower average density overall for manufacturing debris could reflect the intentional discard of more fractured and weathered stone. Such material tends to have a higher of chlorite (a mineral with an average density of around 2.65) content and so would naturally have a lower SG than less fractured/weathered forms of vesuvianite-grossular. Conversely, the high mean density for unfinished vesuvianite-grossular beads may indicate that the stone becomes more difficult to work as its grossular content increases. Recall that grossular can have a hardness of up to Mohs 7.5 while the hardest drills used by Harappans (made of microcrystalline silicate or "Ernestite") were only around 7. Thus, partially perforated bead blanks (such as the one pictured in Figure 9.4) were likely discarded because their high grossular contents (indicated here by their high densities) rendered them undrillable.

Figure 9.3: Specific gravity range and mean of different types of vesuvianite-grossular artifacts from Harappa

Artifact type	*amount*	*SG range*	*mean SG*
Unweighed "micro-debitage"	361	n/a	n/a
Weighed debris fragments	161	2.98 to 3.52	3.28
Unfinished beads	10	3.30 to 3.50	3.35
Finished ornaments	11	3.32 to 3.45	3.31

Figure 9.4:Unfinished bead H96/7106-6 (SG = 3.50)



Is vesuvianite-grossular Harappan "jade"?

In an appendix to his report on beads excavated at Harappa, Beck listed (1940) five examples composed of "jadeite." Beads said to be made of the same mineral were also reported among jewelry hoards discovered in the later levels of Mohenjo-daro's DK (Mackay 1931c: 519, Marshall 1931b: Plate CXLVIII a) and HR areas (Marshall 1931b: Plate CL; Sahni 1931a: 194). That these artifacts were genuine "jade" (either the mineral jadeite or the rock nephrite) has long been taken for granted by scholars (Chakrabarti 1990: 142; Lahiri 1992: 78-79; Mackay 1938: 498; Piggott 1950: 174; Ratnagar 2004: 149; Wheeler 1968: 80) who point to the supposed presence of that stone as evidence for Harappan long-distance trade with peoples in source areas external to the Greater Indus region – namely in Central and/or East Asia. Vidale and Bianchetti have suggested (1997) that the "jade" beads reported from early excavations at Harappa and Mohenjo-daro may actually be composed of vesuvianite-grossular. In this section, I evaluate that possibility.

Some of the supposed "jade" beads from those early excavations are pictured at the beginning of this chapter. HM5339 in Figure 9.1 A is from the Harappa Museum collection. Horace Beck did not provide details in his report as to how he came to the conclusion that beads like this one were composed of "true jadeite" (1940: 402). He did, however, note that they seemed to be "unusually transparent" for jade (ibid.). A portion of a necklace with "jade" beads from the DK Area hoard at Mohenjo-daro is pictured in Figure 9.1 B, *top image.* A.L. Coulson of the Geological Survey of India employed a variety of basic mineralogical tests in the analysis of these artifacts and others like them (Coulson 1931: 538-42). The density of the 23 examples he studied ranged from 3.225 to

3.395, with an average of 3.34. The hardness of two of those beads was judged to be 7.5 and the refractive index (RI) of one determined to be 1.651 ± .002. Like Beck, Coulson noted that the green to yellowish-green material seemed to be "more translucent than most varieties of jade" (ibid.: 542) and twice referred to it (ibid.: 539, 542) as a "peculiar" form of that stone. The finished condition of the ornaments obscured the stone's fracture and texture – characteristics that could have provided additional clues as to its identity.

Given the limited information that Coulson and Beck were able to glean from the beads they examined, the conclusion that they were made from jadeite is understandable. The shade of green the stone exhibits is reminiscent of that mineral and, although somewhat rare, highly translucent varieties (such as *Imperial Green Jadeite*) are known to occur (Levy and Scott-Clark 2001). Moreover, the measured SG and RI values of the Mohenjo-daro beads were consistent both with published values for jadeite and those of the jade specimens that Coulson examined in the Geological Survey of India's collections (particularly those from Burma). There are, nonetheless, several reasons to believe that the beads in question were misidentified and are actually composed of vesuvianite-grossular.

To begin with, the co-occurring variety of vesuvianite and grossular garnet ("californite") has a very "jade-like character and may pass for the genuine material, especially" since it and jadeite have *overlapping* specific gravity values (Webster 1975: 232). So, although it is the case the densities of the beads Coulson tested from Mohenjo-daro all fell within (or very near) the density range of jadeite (SG 3.24 to 3.43 – Deer et al. 1992: 192), they were also equally consistent with the density range of vesuvianite-grossular. Another important point to observe is that Coulson's estimated hardness of the

"jade" beads was Mohs 7.5. That value is much more characteristic of a stone containing grossular than it is of jadeite, which has a *maximum* hardness of Mohs 7 (Schumann 1977: 154) and is usually more around Mohs 6 (Deer et al. 1992: 192). Finally, vesuvianite-grossular is sold as "jade" in the bazaars Pakistan today. I have analyzed samples purchased in both Peshawar and Quetta that are mineralogically analogous to artifacts composed of that stone at Harappa. Perhaps most significantly, the visual appearance of this material is *identical* to the "jade" beads in question. Given this and the other physical characteristics that those beads exhibit, I find it far more probable that they were made from vesuvianite-grossular rather some "peculiar" form of jadeite.

The above conclusion is strengthened by the fact that there were multiple sources of vesuvianite-grossular in South Asia available to consumers in the Indus Valley (discussed in the next section) but there were few sources of genuine jade in the region. As I argued in Chapter 4, a distinctive spinach-green truncated conical amulet from a Period 3B burial at Harappa is, quite likely, made of nephrite jade like that identified in conglomerate beds of the Middle/Upper Siwaliks of northern Pakistan, which is the only reported South Asian jade occurrence that holds up to much scrutiny. Krishnaswamy (1979: 499) writes that jade can be found in Tamil Nadu, Madhya Pradesh and Gujarat. An examination of his primary source material, however, suggests that these are not actually sources of jadeite or nephrite. For example, he cites C.S. Middlemiss (1921: 69) who described two types of material in northeast Gujarat (a translucent white pyroxene and a pale green tremolite-amphibole) that, when polished, were very "handsome" and "jade-like." Middlemiss even suggested that they might make good ornamental stone. However, he pointed out that neither was dense

enough to qualify as true jade. On the subject of jadeite, Lahiri cites (1992: 80) a report (Singh and Gupta 1987) describing in situ pods of that mineral in the ultramafic rocks of the Shyok Ophiolite, Leh District, Jammu and Kashmir. Although material from that locality might actually be genuine (a more detailed mineralogical analysis is needed to confirm this), the fibrous material described there, while greenish in color, does not sound as if it much resembles the highly translucent stone found at Mohenjo-daro and Harappa.

Of course, nothing presented above definitively proves that the so-called "jadeite" beads from early excavations at Indus Civilization cities are actually made from vesuvianite-grossular. In order to do that it would be necessary to directly test them. However, I can state that I know of no other variety of rock or mineral (including genuine jadeite) that accounts for the appearance and reported properties of those beads more satisfactorily than vesuvianite-grossular. I can also report that this stone has now been positively identified at Mohenjo-daro (Appendix 9.2). Six small translucent green stone fragments (three of which are pictured in Figure 9.1, *bottom image*) were provided to me by Dr. Massimo Vidale, who collected them from the site's "Moneer" Area (Vidale 1987a, 1990) during the IsMEO-Aachen University project (Jansen and Urban 1984). These samples are mineralogically analogous to vesuvianite-grossular debris fragments found at Harappa. Debris fragments and beads made of a visually identical stone are found in the collection of excavated material from the Indus city of Dholavira, which is currently housed at Purana Qila in New Delhi. In the summer of 2007, I subjected these to the same non-destructive specific gravity testing used to evaluate green stones at Harappa and found them to have desity values consitent with vesuvianite-grossular (a.k.a. "Harappan Jade").

Where did the vesuvianite-grossular acquired by Harappans come from?

In this section, I attempt to shed light on the question of where Indus Civilization craftspeople obtained the massive variety of vesuvianite-grossular that they used to make beads and amulets. I first examine potential sources of that stone in India and Pakistan. While doing this brief mention is also made of certain geologic occurrences that I do *not* consider to be potential sources, either because they are too distant (those in far eastern India for example) or because the nature of the stone found at those locations is not the same as the material used by Harappans. After reviewing both potential and unlikely sources, I present the results of an INAA study in which vesuvianite-grossular samples collected from three occurrences in three different regions – Rajasthan, Balochistan and the NWFP, were compared to fragments of that stone recovered from Harappa and Mohenjo-daro. All archaeological sites, geologic occurrences and geographic regions discussed in this section are identified on figures 9.5 and 9.6.

Potential vesuvianite-grossular sources in India

Scholars studying vesuvianite-grossular artifacts found at sites in both South Asia (Vidale and Bianchetti 1997: 951-52) and West Asia (Sax 1991: 113) have pointed to the Indian state of Rajasthan as a possible source of that stone. Although the region is indeed rich in many varieties of garnet (Geological Survey of India 2001b: 64-65), grossular garnet (green or otherwise) has not yet been reported in the geologic literature as occurring there. Vesuvianite, on the other hand, is known (although not particularly well) from several places in Rajasthan. Middlemiss (1921: 20) made an oblique reference to a sample of vesuvianite in the Tonk Museum, which was said to be from a quarry near Rer in the

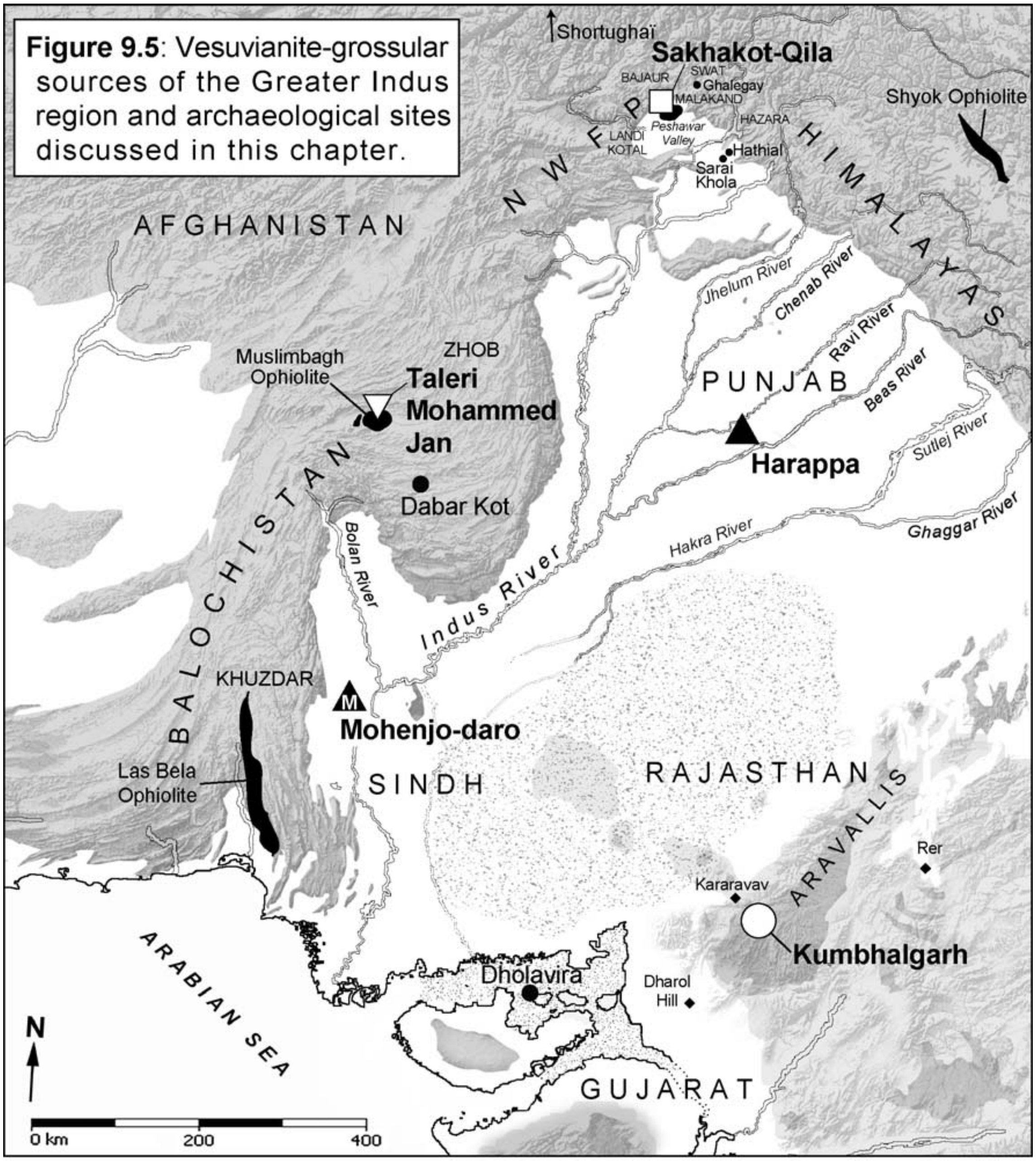


Figure 9.5: Vesuvianite-grossular sources of the Greater Indus region and archaeological sites discussed in this chapter.

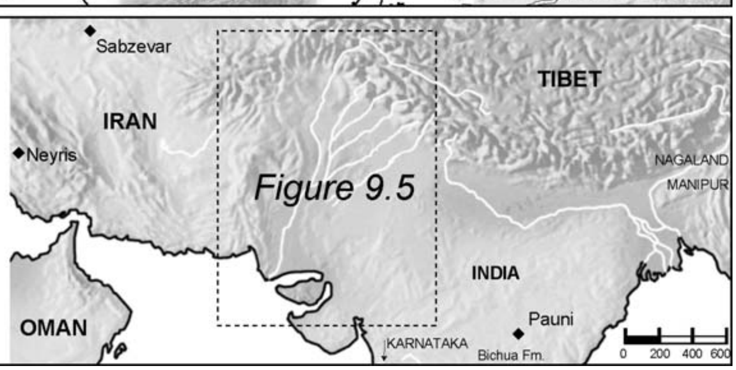


Figure 9.6: Occurences of vesuvianite, grossular, or both outside of the greater Indus region.

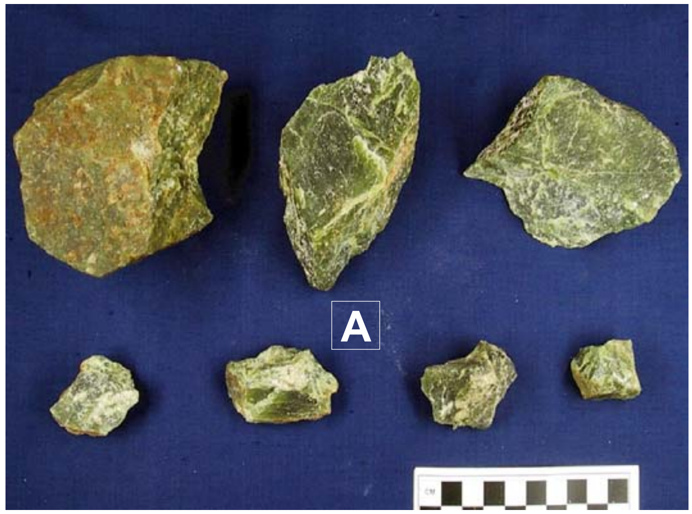
Figure 9.7: Massive vesuvianite and vesuvianite-grossular samples from three South Asian sources

Source

A. Kumbhalgarh Forest, Rajsamand District, Rajasthan

B. Kot/Musa Mena area Sakhakot-Qila ophiolite, Malakand/Mohmand, NWFP

C & D. Taleri Mohammed Jan, Muslimbagh ophiolite, Zhob District, Balochistan





eastern part of the state. However, no other information was provided on either the sample (its color, to crystal habit, etc.) or its source. Vesuvianite is mentioned as a mineral associated with skarn rocks round Kararavav in the Pali District of southwestern Rajasthan (Rathore 1991). Although no further details were given regarding that occurrence, it is likely related to another one nearby within Kumbhalgarh Forest Reserve in the adjacent Rajsamand district, which I first learned about in 2003.

In March of that year, while visiting with a jeweler in Udaipur, Rajasthan, I was shown a string of semi-translucent green beads along with the raw stone from which they were made. The green hue of the beads was somewhat deeper than the typical vesuvianite-grossular artifact from Harappa but the stone, although highly fractured, was massive, compact and seemed to be fairly dense, which was much more like vesuvianite-grossular than other locally available green stones such as serpentine or aventurine quartz. I arranged to meet the man from whom the jeweler purchased the stone. That man was unwilling to either take me to the stone's source or give me much information about its location except to say that it was "in the forest." I was, however, able to acquire many samples, some of which can be seen in Figure 9.7 A. A few weeks later I related this story to N.K. Sood, Director–Geological Survey of India at Jaipur. Although he was not certain at the time of the stone's composition, he was able to confirm that it could be found in Kumbhalgarh Forest Reserve, Rajsamand District of southern Rajasthan. He said that Bhil tribesmen in the area were mining the stone and showed me a sample of that material that they had provided to him. It appeared to be identical in every way to the samples that I had acquired from the stone merchant living near Udaipur.

I analyzed the Kumbhalgarh stone using XRD upon my return to Madison and found it to be pure vesuvianite (Appendix 9.3). Although there was no indication of grossular or chlorite in the XRD peak profile of the single sample that I studied, the same is actually true of many of the debris fragments analyzed from Harappa. As I noted above, the appearance of the Kumbhalgarh stone is slightly different than typical Harappan vesuvianite-grossular. Still, among the flakes at Harappa there are a few deeper green and highly fractured examples. That such material was sometimes used to make ornaments is evident from the truncated conical amulet numbered H90-3037-36, which is pictured in Figure 9.1 A. Therefore, Kumbhalgarh Forest could be a potential source of this stone.

Elsewhere in India, green garnet occurs at several locations in Karnataka (Parthasarathy et al. 1999; Viswanathiah et al 1979; Somasekar and Naganna 1966) but it is of the uvarovite garnet variety. Grossular garnet and vesuvianite are found together (but only as small grains) in the calc-schists of the Bichua formation of central India (West and Sharma 1989: 497). A showing of vesuvianite was reported from a chromite mine in the Pauni ultramafics of Maharashtra but no information was given as to its color (Mahajan and Singh 1984: 11). Vesuvianite and vesuvianite-grossular occur in veins a few inches across at Dharol Hill in northeast Gujarat (Middlemiss 1921: 20-21). The material at this location is described as translucent to transparent brown, however.

Translucent green vesuvianite-grossular can be found near the border Myanmar border in the far eastern part of India. Rodingitized volcanic dykes in ophiolitic rock in the states of Manipur (Shukla 1989) and Nagaland (Ghose et al. 1986) are reported to contain large masses of this material. Although it is not impossible that massive vesuvianite-

grossular from these distant sources found its way to Harappa (over 2200 km away), there were much closer sources in regions that today are within modern Pakistan.

Potential vesuvianite-grossular sources in Pakistan

There are three regions in Pakistan where vesuvianite or vesuvianite-grossular has been positively identified: the NWFP, northern Balochistan and southern Balochistan

Massive varieties of translucent green vesuvianite-grossular occur at several places in the bordering Malakand, Mohmand and Bajaur Agencies of the NWFP (Kazmi 1995b: 286; Kazmi and Jan 1997: 477). Volcanic dykes running through the Sakhakot-Qila ophiolite contain extensive lenses of massive vesuvianite-grossular with occasional chlorite impurities and inclusions of chromite and magnetite (Qaiser et al. 1970, 1972; Ahmed 1987a, 1988a, 1988b). Qaiser and others (1970: 735) noted that stone from this area "has been sold locally as 'jade'." Samples from this source (Figure 9.7 B) were provided by the late Dr. Syed Hamidullah of the Center of Excellence in Geology, University of Peshawar.

Near the village of Taleri Mohammed Jan in the Zhob District of northern Balochistan, the metasomatic alteration of a dolerite dyke in the Muslimbagh ophiolite resulted in the formation of vesuvianite, grossular and clinochlore (Bilgrami and Howie 1960, Bilgrami 1960, Bilgrami 1963: 1176-77). In May of 2001, I visited this occurrence with Dr. Khalid Mahmood of the Center of Excellence in Mineralogy, University of Balochistan, Quetta. We collected samples from an area of rodingite bearing a vein of translucent, but highly fractured green vesuvianite (Figure 9.7 B). Although no evidence of ancient mining was observed here, the massive talus-like debris field surrounding the source suggested an extended and/or intensive period of exploitation. Local residents

reported that during the British Era much larger masses of material could be found at this location. Kazmi noted (1995b: 286) that vesuvianite had recently reappeared in the bazaars Quetta indicating the possibility that local tribesmen had discovered a new source. I obtained several samples of vesuvianite-grossular in Liaqat Bazaar, Quetta during the spring of 2001, which were said to be from a new source in the Muslimbagh ophiolite.

Translucent green crystals occurring in the northern part of the Las Bela ophiolite in the Khuzdar District, southern Balochistan were identified using XRD as vesuvianite by Armbruster and Gnos (2000: 112). The crystals were, however, all less than 1 mm in size. Although no massive bodies of vesuvianite-grossular have yet been reported in this area, the geology of the region (rodingization of calcium-rich rock) is such that they could exist.

An INAA comparison of vesuvianite-grossular artifacts to samples from three sources

Ten vesuvianite-grossular artifacts (seven debris fragments from Harappa and three from Mohenjo-daro) were compared to samples from three potential geologic sources (Sakhakot-Qila, Taleri Mohammed Jan and Kumbhalgarh Forest) in South Asia using INAA-derived elemental data, canonical discriminant analysis (CDA) and cluster analysis (CA). Details relating to sample preparation, INAA and data evaluation using CDA and CA have already been discussed in Chapter 2. The INAA results for the artifacts are listed in Appendix 9.4 and those for the geologic sources can be found in appendices 9.5 and 9.6.

Although the seven vesuvianite-grossular artifacts from Harappa in the comparative set (pictured in Figure 9.1 A, *bottom image*) represent a mere 1.3% of the sub-assemblage of that rock variety, they were carefully selected to be as spatially and temporally representative as possible (see columns two through four of Appendix 9.4 for information

on their Period, Mound and Trench associations). All are from stratigraphically secure contexts (together they represent around 4% of the 180 vesuvianite-grossular artifacts from such contexts). There is at least one example in the set from each chronological phase in which this variety of stone has been recovered (periods 1, 3B, 3C and 5). As only one vesuvianite-grossular flake each was found in periods 1 and 5 levels, and only four flakes are associated with Period 3B levels, the analysis of these artifacts represent a 100%, 100% and 25% (respectively) sample of those chronological sub-assemblages. Each of the four major mounded areas at the site is represented in the set by at least one artifact.

The three vesuvianite-grossular artifacts from Mohenjo-daro (pictured in Figure 9.1 B, *bottom image*) were provided by Dr. Massimo Vidale. All are surface finds that he collected during his research on lapidary craft industries at the site's "Moneer" Area (Vidale 1987a, 1990). The three artifacts (MDV-1, MDV-2 and MDV-3) are from among the six flakes I previously analyzed using XRD (Appendix 9.2).

Twenty-two samples from three vesuvianite-grossular sources comprise the set of geologic comparative material. Six are from rodingite veins in the Sakhakot-Qila ophiolite, Malakand/Mohmand agencies, NWFP. Nine are from Taleri Mohammed Jan, Zhob District, Balochistan. Seven (obtained from a stone merchant) are from the reported vesuvianite occurrence in Kumbhalgarh Forest, Rajsamand District, Rajasthan.

INAA of the comparative set yielded 13 elements (Al, Ce, Co, Cr, Eu, Fe, Mn, Na, Sc, Sm, Sr, U and V) suitable for multivariate statistical analysis. These data were first examined using CDA, the results of which are graphically displayed in Figure 9.8 (Appendix 9.7 lists the standardized (canonical) discriminant function coefficients for that

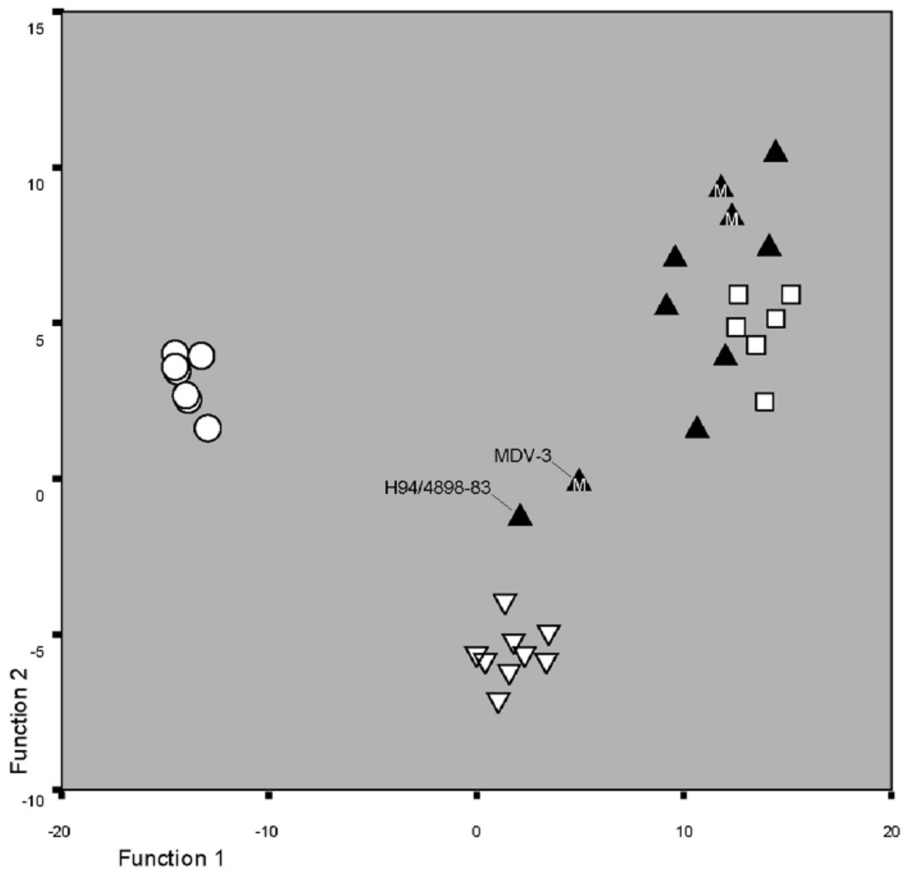


Figure 9.8: Archaeological Vesuvianite-Grossular vs. Three Geologic Sources

Canonical Discrimanant Functions based on
Al Ce Co Cr Eu Fe La Mn Na Sc Sm Sr U V

▲ Archaeological - Harappa

▲ Archaeological - Mohenjo-daro

▽ Geological - Taleri Mohammed Jan, Baluchistan

○ Geological - Kumbhalgarh Forest, Rajasthan

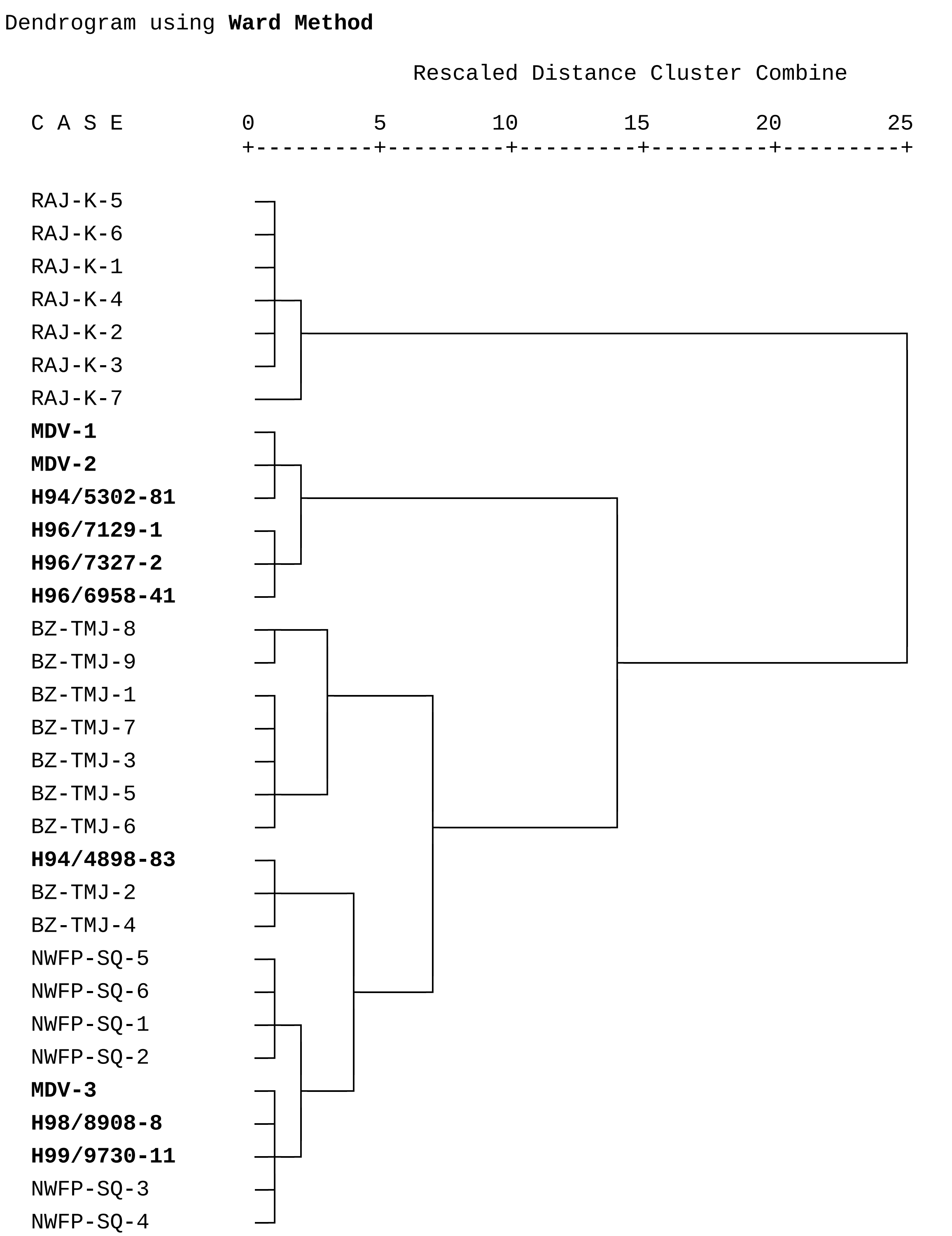
□ Geological, Sakhakot-Qila, N.W.F.P.

figure). Outstanding visual separation between the three geologic sources was achieved. Application of the leave-one-out classification function resulted in a 100% grouped sample cross-validation success rate, which indicates that the three sources are also highly distinct statistically. The predicted group member membership for eight of the ten artifacts was the Sakhakot-Qila source. Two artifacts – one from Harappa (H94/4898-83) and one from Mohenjo-daro (MDV-3) were predicted to belong to the Taleri Mohammad Jan source. Both of these are labeled on Figure 9.8.

The vesuvianite-grossular artifact and source sample data were also examined using hierarchical cluster analysis. Multiple clustering strategies were employed. Figure 9.9 is a dendrogram generated using Ward's method. Six alternate strategies can be seen in Appendix 9.8. All produced dendrograms that were remarkably similar. With regard to the geologic sources, the Kumbhalgarh Forest samples always formed a cluster that was completely distinct from the other two geologic sources examined. Those two – Sakhakot-Qila and Taleri Mohammad Jan, together formed a second larger cluster indicating that, geochemically, they were much more similar to one another. This is not altogether surprising as they are both associated with the ophiolite formations that are found intermittently along the northern and western margin of the Indus Basin. Within that second large cluster, however, the Sakhakot-Qila and Taleri Mohammad Jan sources either overlap minimally or, depending on the clustering strategy used, not at all.

Turning to the artifacts, once again, none even remotely resemble the Kumbhalgarh source. An examination of the dendrograms indicates that the same four artifacts consistently group closely with the either the Sakhakot-Qila or Taleri Mohammad Jan

Figure 9.9: Hierarchical cluster analysis of the vesuvianite-grossular comparative set



sources. Sample H94/4898-83 groups closely with the Taleri Mohammad Jan samples while H98/8908-8, H99/9730-11 and MDV-3 groups with those from Sakhakot-Qila. (note that CDA had previously assigned MDV-3 to the Taleri Mohammad Jan source). The six remaining artifacts consistently grouped together to form a cluster that, although clearly more closely related to those two sources than to the Kumbhalgarh source, is still very distinct in itself. This suggests that these artifacts may be from a fourth vesuvianite-grossular source that is not represented among the geologic sample set. As previously indicated by CDA, the artifacts forming that cluster are statistically more closely related to the Sakhakot-Qila source than they are to the Taleri Mohammad Jan source. It is probable, therefore, the unknown source is one of the several as yet of un-sampled vesuvianite-grossular deposits reported to exist in the Mohmand or Bajaur agencies of the NWFP.

In conclusion to this section, the ten vesuvianite-grossular artifacts from Harappa and Mohenjo-daro analyzed for this study almost certainly came from an occurrence located along the northwestern margin of the Greater Indus region rather than from Rajasthan. Most seem to have been derived from an NWFP source but a few may have come from one in northern Balochistan. Although no Indus Civilization settlements can be found in the immediate vicinity of either source, both lie along what *may* have been major trade and communication routes during that the third millennium BC. Harappans might have passed through or near the Malakand or Mohmand areas of the NWFP on their way to and from the outpost of Shortughaï in northern Afghanistan. Taleri Mohammad Jan lies at the southern end of the Zhob Valley (an important route through northern Balochistan today) and is around 130 km northwest of the Indus Civilization settlement of Dabar Kot.

Was vesuvianite-grossular exported to Mesopotamia from the Greater Indus region?

In reference to reports of artifacts made of vesuvianite-grossular at third millennium BC sites in Mesopotamia, Vidale and Bianchetti (1999) hypothesized that this variety of stone may have been exported to that region from South Asia. Earlier, Margaret Sax (1991) had made a similar suggestion with regard to first millennium B.C Mesopotamian cylinder seals composed of the same material. In this section, I first briefly discuss the possibility that Harappans exported vesuvianite-grossular west of the Greater Indus region. I then review potential sources of that stone that, as compared to those in South Asia, may have been more accessible to consumers in western Asia.

There is no reason why vesuvianite-grossular (or any other material for that matter) could not have been traded from South Asia to the Mesopotamia region during the third millennium B.C or later. As previously noted, green stone fragments and beads visually identical to the vesuvianite-grossular artifacts positively identified at Harappa and Mohenjo-daro are present in collections from the Indus Civilization city of Dholavira in northern Gujarat (*personal observation*). From there and other southern coastal settlements, this stone could have easily been transported to consumers in West Asia via maritime trade routes, which were clearly active at this time (Possehl 1997a). Overland exchange could have taken place via any number of pathways (many of which are outlined in Chakrabarti 1990 and in Ratnagar 2004). Vesuvianite-grossular might very well have been moved along the same routes through which "inter-cultural" style chlorite vessels were traded from highland Iran to inland settlements across a broad area extending from the Indus Valley to West Asia (Kohl 1975; Lamberg-Karlovsky 1993). Indus Civilization

peoples clearly had the capability and connections necessary to export this valuable stone to consumers the west. The pertinent question now is whether or not Mesopotamian consumers had access to alternate sources of vesuvianite-grossular.

A review of the geologic literature reveals numerous potential vesuvianite-grossular sources that, as compared to those of northwestern South Asia, would have been closer to consumers in Mesopotamia. A massive occurrence of this stone is reported (Alberti et al. 1976) in rodingitized rock in the Sabzevar ophiolite, Khorassan Province, northeastern Iran (see Figure 9.6). Nearer to the Mesopotamian heartland (not pictured on Figure 9.6) is a vesuvianite-grossular source in the Neyriz Ophiolite Complex of the southern Zagros Range, Iran (Adib and Pamic 1979). Stone from that locality might have been acquired through Mesopotamian interaction with the ancient groups inhabiting those resource-rich highlands (Henrickson 1994). The grossular described (Ahmed 2002) in the al-Madhiq region of southwest Arabia is brownish-red in appearance but it is possible that there are sources of green-colored stone elsewhere in western Asia that remain to be identified. Ophiolites containing the skarn rock / rodingite formations in which massive vesuvianite-grossular tends to form are found a various other points along northern Zagros Range and into the highlands of Anatolia (Cogulu 1980; Schandl and Mittwede 2001). A source of the massive green variety could eventually be found in those regions.

Although Harappans could have exported vesuvianite-grossular to Mesopotamia, consumers in that region probably had access to closer sources of the stone. To test Vidale and Bianchetti's hypothesis (1999), it will be necessary to compare Mesopotamian artifacts with sources analyzed in this chapter and samples collected from West Asian occurrences.

Vesuvianite-grossular at Harappa and its association with "Ernestite"

In this final section, I examine the spatial and temporal distribution of vesuvianite-grossular artifacts at Harappa and discuss what I believe is an interesting and important association between that material and another variety of rock found at the site – "Ernestite."

The 543 artifacts classified as vesuvianite-grossular at Harappa comprise 0.96 % of the site's entire stone and metal assemblage – just short of the (admittedly arbitrary) 1% value above which I defined materials as major rock or mineral varieties. The only stones used more by bead-makers were steatite and microcrystalline silicates. Vesuvianite-grossular is three times as abundant at Harappa as lapis lazuli, which is a material that has received considerably more attention from scholars (see Appendix 4.4). A similar pattern may exist at Mohenjo-daro. Few lapis lazuli artifacts have been reported at that site but it now appears as if numerous items, such as the beads previously identified as "jade" and rock fragments once thought to be serpentine (Vidale 2000: 42), are composed of vesuvianite-grossular. Whether or not that stone was as widely distributed across the Indus Civilization as lapis lazuli remains to be determined but, as I have already noted, it seems to be present as far south as Dholavira. Although it may eventually be discovered that vesuvianite-grossular artifacts were relatively abundant and widespread, the evidence from Harappa indicates that the stone's use, at least at that site, was rather restricted in space and time.

The numbered trenches and labeled areas on Figure 9.10 indicate those parts of Harappa from which vesuvianite-grossular artifacts have been recovered. The inset pie-chart on that figure shows how this material sub-assemblage was differentially distributed among site's major areas. The first four columns of Figure 9.11 provide a more detailed

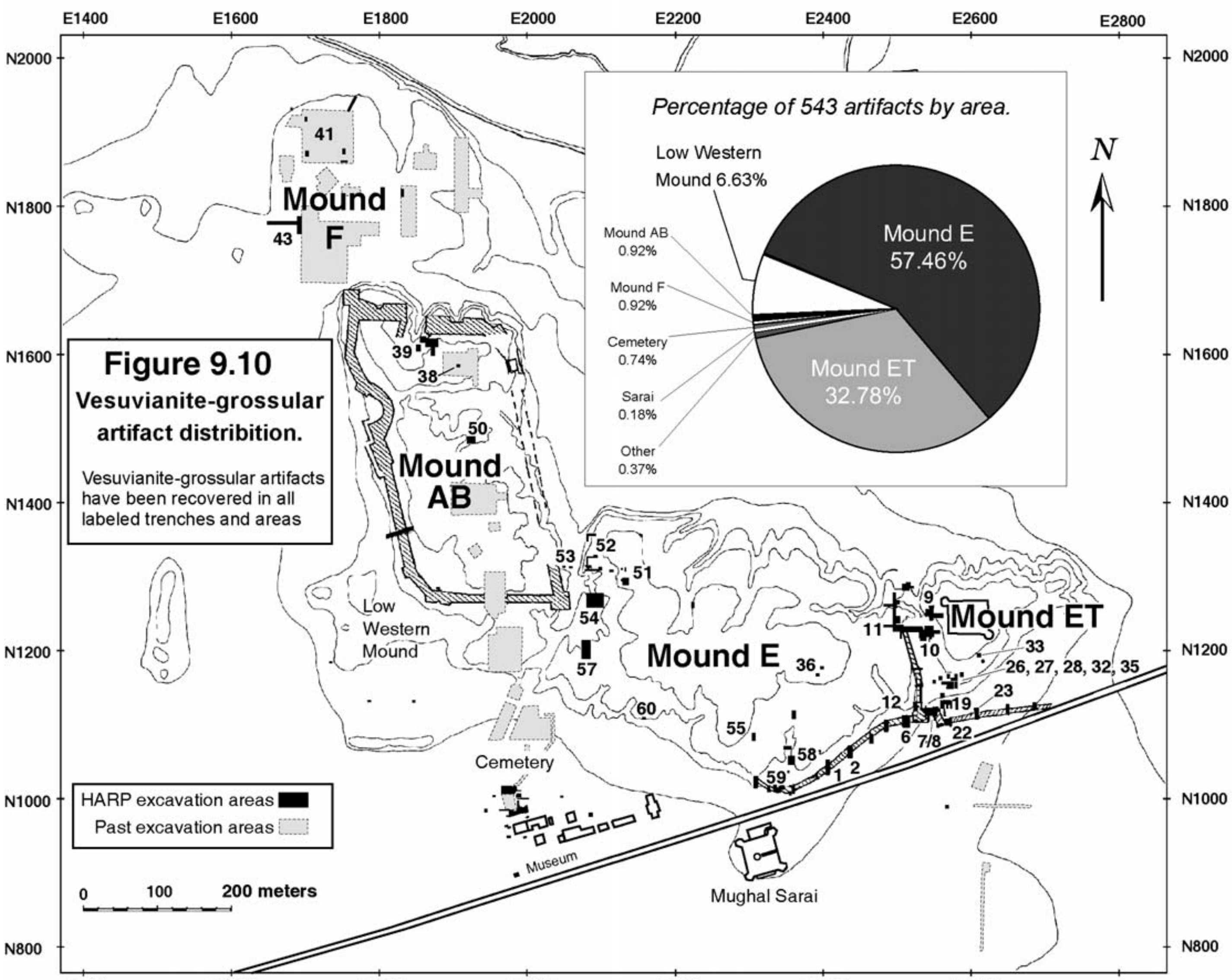


Figure 9.10
Vesuvianite-grossular artifact distribution.

Vesuvianite-grossular artifacts have been recovered in all labeled trenches and areas

Figure 9.11: Spatial distribution of all vesuvianite-grossular and "Ernestite" artifacts at Harappa							
Vesuvianite-Grossular (n = 543)					**"Ernestite"** (n = 75)		
debris	*unfinished beads*	*finished beads*	*amulets*	**Mound E-ET**	*drills*	*blocklets / blanks*	*debris*
2				Trench 1	1		
3				Trench 2			
1				Trench 6			
1				Trench 7	1		
2				Trench 8			
1				Trench 9			
10	1			Trench 10	1		3
2				Trench 11	1	1	2
2				Trench 12			
24				Trench 19	1		
2				Trench 22	1		
7				Trench 23			
13				Trench 26			
37	1			Trench 27	3		5
31	1	1		Trench 28	7	1	4
8				Trench 32	2		
1				Trench 33			
3				Trench 35			
235	4			Trench 36	2	3	9
5				Trench 51			
2		1		Trench 52			
1				Trench 53			
5				Trench 54			3
1				Trench 55			
3				Trench 57			1
4			1	Trench 58			
3		1		Trench 59			
		1		Trench 60			
67	1	1		Survey on E/ET	6	1	8
				Mound AB			
1				Trench 38			
3				Trench 39			
	1			Trench 50			
				Survey on AB			4
				Mound F			
	1			Trench 41		1	
3			1	Trench 43			
				Other			
1				Mughal Sarai			
4				Cemetery area		1	1
34		2		Low Western Mound			1
		2		Unknown (Harappa Museum)			
522	*10*	*9*	*2*	*TOTALS*	*26*	*8*	*41*

picture of the sub-assemblage's composition and its distribution among those excavation trenches and survey areas from which it was recovered. Slightly more than 91% of all vesuvianite-grossular artifacts at Harappa came from mounds E and ET (the heaviest concentration is in the area straddling the east-southeast side of mound E and the west-southwest side of mound ET). Fifty-three vesuvianite-grossular artifacts were recovered elsewhere at the site. The majority of those (n = 41) came from off-mound Harappa Period dumps above the cemetery area and the Low Western Mound. A mere five were found on mound AB and only four on Mound F. One flake was found in the area of the Mughal Sarai (just to the south of Mound E). Lastly, there are two beads from the Harappa Museum collection included in the vesuvianite-grossular sub-assemblage. Although their precise context is unknown (they did not possess any identifying numbers), it is not unlikely that they are from among the five "jadeite" beads listed in Beck's report (1940: 413-414), four of which reportedly came from Mound F and one from Mound D (≈ Area J near the Low Western Mound and south of Mound AB).

Three hundred sixty-three (or approximately two-thirds) of the 543 vesuvianite-grossular artifacts at Harappa are from surface or disturbed deposits. Of the remaining 180 artifacts recovered from stratigraphically secure deposits (see Figure 9.12 *third row*), all but six come from Period 3C levels. Four were recovered in Period 3B levels. A single flake was found in Ravi Phase (Period 1) levels (Trench 39, Mound AB). Although the flake appears to be from a secure excavation lot, there is a possibility that it is a later phase artifact that was re-deposited by rodent action, which is common in those levels (although great care is taken to identify such disturbances). Another individual flake of vesuvianite-

Figure 9.12: Temporal distribution and shared lot association of all vesuvianite-grossular and "Ernestite" artifacts from *stratigraphically secure* contexts at Harappa. (*np* = not present)							
Period	**1**	**2**	**3A**	**3B**	**3C**	**4/5**	**Shared secure lots** (n=11)
Vesuvianite-Grossular (n = 180 in 77 lots)	1	*np*	*np*	4	174	1	14.3% of secure lots containing vesuvianite-grossular also contain "Ernestite"
"Ernestite" (n = 40 in 34 lots)	*np*	*np*	*np*	2	38	*np*	32.4% of secure lots containing "Ernestite" also contain vesuvianite-grossular

grossular was found on the floor of a Late Harappan (Period 5) structure (Trench 38, Mound AB). It is possible that this artifact was initially deposited there during Period 5. However, not far away was found a small pot containing mixed beads, amulets, stone fragments and metal scraps (Meadow et al 1996: 5-6, figures 34-36). This find is thought to probably represent the cache of some Late Harappan person who gathered miscellaneous objects from the surface of the site during that period (ibid.: 6; Kenoyer *personal communication*). The vesuvianite-grossular flake found nearby might, therefore, be a loose item from an earlier phase that was collected and brought to this location.

When the spatial and temporal distributions of vesuvianite-grossular artifacts at Harappa are considered together, we see that the four examples from Period 3B levels were all recovered on mounds E and ET (in trenches 9, 10 and 11). Nearly 98% of all examples from Period 3C (170 of 174) also come from those two conjoined mounds. The four artifacts from that period that do not, were recovered on Mound F (n = 3 in trenches 41 and 43) and beneath the Mughal Sarai (n = 1). The two remaining vesuvianite-grossular artifacts of the 180 from secure contexts are the individual flakes from periods 1 and 5 on Mound AB discussed in the preceding paragraph.

I have provided this detailed discussion of the spatial and temporal breakdown of Harappa's vesuvianite-grossular sub-assemblage because I wish to highlight what I believe to be two *genuine* patterns (see Appendix 9.9) related to the use of this stone at the site. Firstly, it appears that Harappan beadmakers probably only used vesuvianite-grossular to create ornaments during periods 3B and 3C. Secondly, it also seems that this activity was almost exclusively confined mounds E and ET during those periods. Admittedly, these patterns could be due, at least in part, to bias stemming from both excavation strategies and physical aspects of the site (discussed in Chapter 4). Recall Figure 4.11. Almost 90% and 80% of all rock and mineral artifacts representing periods 3B and 3C (respectively) were recovered from mounds E and ET. Those phases are, quite obviously, over-represented in the assemblage of stone and metal artifacts from secure contexts. However, every square meter of Harappa's surface has been surveyed by the HARP and this has provided us with a good and representative conception of where major and minor craft activities took place at the site (Kenoyer and Miller 2007; Miller 1994a, 1997, 2000). Figure 9.13 shows the spatial distribution of vesuvianite-grossular artifacts recovered during surveys in combination with those from other non-secure contexts such as brick-robber trenches (this amounts to 363 artifacts in total). The vast majority (87.6%) of such artifacts were found, once again, on mounds E and ET indicating that the most intensive working of that stone took place in that area. Most of the remaining ones (9.9%) came from the Harappan Period dump called the Low Western Mound. If a significant amount of vesuvianite-grossular bead-making activity had taken place on mounds F or AB then the amount of debris recovered from non-secure deposits in those areas should have been far greater than a mere two flakes from each mound.

Figure 9.13: Spatial distribution of all vesuvianite-grossular and "Ernestite" artifacts from *non-secure* contexts at Harappa.

Mound	**F**	**AB**	**E**	**ET**	**Low Western**	**off-mound / unknown**
vesuvianite-grossular *artifacts* (n = 363)	2	2	212	106	36	5
percent of total	0.55%	0.55%	58.4%	29.2%	9.9%	1.4%
"Ernestite" *artifacts* (n = 35)	1	4	18	11	1	0
percent of total	2.9%	11.4%	51.4%	31.4%	2.9%	0%

The spatial patterning of vesuvianite-grossular artifacts at Harappa strongly suggests that the acquisition of that stone and the production of ornaments using it were activities almost exclusively engaged in by residents of mounds E and ET. The reason for this might be because the procurement and distribution of this important resource was something that was closely controlled by individuals or groups living in those areas. On the other hand, it may be the case that, as I will argue shortly, beadmakers in those areas were the only ones who possessed (controlled) the technology needed to perforate this very hard variety of stone. Perhaps both explanations are true.

The spatial patterning of vesuvianite-grossular artifacts also provides another important line of evidence indicating that a close relationship existed between the peoples living and working on mounds E and ET. Recall that in Chapter 4 I showed that grindingstone source usage patterns in those adjoining areas of the site more or less paralleled one another throughout periods 3B and 3C and in surface collections. Below, I show that the same is true for "Ernestite." In the next chapter, I present evidence suggesting that peoples in those areas were the exclusive producers and/or users of alabaster bangles during Period 3. Considered together, these comparable synchronic patterns lend support

to the interpretation that residents of mounds E and ET were probably a part of the same socio-political entity. When those two areas are regarded as a single mound (E-ET) and compared to the other mounds at Harappa, an affirmative answer is provided to this dissertation's third line of inquiry.

The chronological distribution of vesuvianite-grossular artifacts at Harappa clearly shows that the most intensive and, perhaps, exclusive period of acquisition and use of this stone was during the latter part of the Harappa Phase (for reasons already explained, the single flakes found in Ravi and Late Harappan levels *may* be anomalous items that were not originally acquired during those phases). This pattern could indicate that sources were not accessible (either directly or indirectly) to the site's residents prior to that time. Toward the end of the third millennium BC (ca. Period 3C at Harappa), the stone *might* have been acquired indirectly through interaction with Bactria-Margiana Complex (BMAC) peoples of southern Central Asia who were then expanding from that region into the west-northwestern borderlands of South Asia (Hiebert and Lamberg-Karlovsky 1992; Jarrige 1991a) and were evidently present in some capacity at Indus Civilization cities (Meadow 2002; Parpola 2005). As I showed in Chapter 7, the black steatite that was used to carve the small "BMAC-like" wig found in Period 3C levels on Mound F at Harappa appears to be most closely related to steatite occurring in the same geologic formation as one of the vesuvianite-grossular sources examined in this chapter – the Sakhakot-Qila ophiolite. That formation is located on the northern fringe of the Peshawar Valley nearby the Khyber Pass going west into Afghanistan and the Malakand Pass going north into the Swat Valley. If Indus Civilization peoples used these particular passes when traveling to

and from the Harappan outpost of Shortughaï in northern Afghanistan then they themselves might have had direct access to vesuvianite-grossular from the Sakhakot-Qila ophiolite.

Regarding the possibility that vesuvianite-grossular sources were not accessible until latter part of the Harappa Phase, I would point out, again referring to Chapter 7, that the site's residents appear to have been acquiring steatite from deposits in the general vicinity (in the Hazara District and the Khyber Agency) of the Sakhakot-Qila area since the Early Harappa Period. Early Harappans had settlements (Sarai Khola and nearby Hathial) near the eastern edge of the Peshawar Valley and, as indicated by finds at Ghalegay Rock Shelter (Stacul 1987), had at least limited interaction (probably via the Malakand Pass) with peoples in the Swat Valley. The single vesuvianite-grossular flake from Period 1 levels at Harappa (which, of those analyzed, is one of the most geochemically analogous to the Sakhakot-Qila source) might, therefore, have actually been acquired at that time. However, it would have been impossible for Ravi Phase beadmakers to perforate a stone of its hardness using the chert and jasper drills that they then possessed. I believe that this technological limitation is one of the main reasons why vesuvianite-grossular really does not appear in Harappa's archaeological record until the latter part of Period 3.

The only material in Harappa's rock and mineral assemblage from which drills capable of perforating vesuvianite-grossular could have been fashioned was "Ernestite" (support for this statement is provided in Appendix 4.5). To date, 75 artifacts composed of that stone (drill bits, worked blocklets / drill blanks and debris) have been recovered. Their spatial distribution is shown in the last three columns of Figure 9.11. In *all* trenches and areas where "Ernestite" artifacts were recovered vesuvianite-grossular artifacts were also

found. When association at the level of shared stratigraphically secure excavation lot is considered (Figure 9.12 *far right column*), we see that in roughly one out of every three lots (32.4%) in which an "Ernestite" artifact was recovered a vesuvianite-grossular artifact was also present. The 40 "Ernestite" artifacts from secure contexts all come from periods 3B (n = 2) and 3C (n = 38) levels (Figure 9.12 *bottom row*) on Mound E/ET. Nearly 83% of the 35 examples from non-secure contexts are also from that area (Figure 9.13 *bottom row*).

The spatial and temporal distribution patterns of "Ernestite" and vesuvianite-grossular artifacts at Harappa are practically mirror images of one another. This is almost certainly no coincidence. Vesuvianite-grossular could not have been drilled without the use of "Ernestite" bits (holes can be "pecked" through that stone to make very small beads but there is no evidence this was done). Harappans might have had access to the regions where vesuvianite-grossular occurred and even knowledge of the stone's existence as early as the Ravi Phase but they did not then possess the technology needed to turn it into finished beads. That each variety of stone appears in the archaeological record at exactly the same time *when* (ca. periods 3B and 3C) and, largely, in the same places *where* (Mound E/ET) beadmakers were using the other one should come as no surprise. In Chapter 13, I discuss the implications of the differential distribution of this and other rock varieties at Harappa.

Chapter conclusion

Vesuvianite-grossular from sources in the NWFP and, to a lesser extent, northern Balochistan, was acquired during periods 3B and 3C, and was mainly used by residents of mounds E and ET. In the next chapter, I examine the acquisition of alabaster – a more widely available variety of stone that was used to create both ornaments and large objects.

Chapter 10

Alabaster acquisition networks

Chapter 10 – Alabaster acquisition networks

Chapter introduction – The different forms of gypsum at Indus Civilization sites

The mineral *gypsum* – hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$), is found in many forms at Indus Civilization sites. Transparent tabular crystals of gypsum known as *selenite* have been recovered at Harappa. Gypsum mortar was sometimes used for the "pointing" (filling the joints) of brick masonry at that site (Vats 1940: 12-13) and at Mohenjo-daro (Mackay 1938: 162). At Dholavira, the inlayed lettering of what appears to have been a large signboard was composed of a white gypsum paste (R.S. Bisht *personal communication* 2004). Naturally precipitated gypsum has been found encrusting artifacts at Mohenjo-daro (Mackay 1938: 162, 525) and in the soils around Harappa (Amundson and Pendall 1991: 18). The white coating on the exterior of pots in some burials at Harappa, which some believe to be deliberately applied gypsum plaster (Strahan 1991), may actually be natural encrustations. In this chapter, I identify the sources from which residents of Harappa acquired the massive variety of gypsum known as *alabaster*.

The name "alabaster" has been used to describe ornamental stones of varying chemical compositions. "Oriental" or "Egyptian" alabaster is actually *travertine* – calcium carbonate ($CaCO_3$) and is sometimes also called "onyx marble" (el-Hiwanni and Loukina 1972; Webster 1958). Recall the small stone ring (Figure 4.7 B) mentioned in Chapter 4 that looks much like the travertine quarried today in the Chagai Hills of Balochistan (Ahmad 1975: 124-128). This is *not* the type of material that is under examination here. Genuine alabaster is the compact, massive form of gypsum. Gypsum alabaster (hereafter just alabaster) is semi-translucent in thin pieces and has a sugary texture that becomes

satiny when polished. Purer varieties are white to pink in color. These qualities, along with the fact that it is relatively common and easily carved (Mohs hardness of 2), made it a popular ornamental stone in many areas of the ancient world (Rapp 2002: 123-127). The Indus Civilization was no exception. A wide range of alabaster objects have been found at Indus settlements including large and small rings, whorls, mace-heads, bangles, beads, cubical weights, discs, balls, inlays, pendants, “gamesmen”, lattice-screens, plugs, bowls and bottles (see Lahiri 1992 for a site by site listing of alabaster artifacts).

Past researchers (Gale et al. 1988) have successfully employed a combination of sulfur isotope and strontium isotope analysis to determine the geologic provenience of gypsum artifacts from Mycenaean Greece. Using these same methods, a set of alabaster artifacts from Harappa is compared to geologic samples from multiple locations in three potential source formations surrounding the Indus Valley. This study is supplemented with isotopic analyses of a small set of artifacts from three other Early Harappan and/or Harappan period sites as well as with the characterization of an unusual type of quartz recovered at Harappa, which may derive from one of the alabaster sources under consideration. Before presenting the details of those studies, however, I first provide an overview of the forms and contexts in which alabaster is found at the site of Harappa.

Alabaster at Harappa

Alabaster is one of the most abundant of the minor rock and mineral varieties in Harappa’s lithic assemblage. To date, 422 artifacts made of this stone have been recovered during excavations by the HARP (Figure 10.1). Numerous other examples were described in M.S. Vats’ original excavation report (Vats 1940). More than half (n=222) of this

Figure 10.1: Alabaster artifacts excavated by the Harappa Archaeological Research Project (1986-2001)								
context	**Mound AB**	**Mound F**	**Mound ET**	**Mound E**	**Cemetery**	**Sarai**	**Other**	*total*
surface or disturbed	106	9	10	69	1	2	13	*210*
Period 3C	38	46	38	46	8	3	.	*179*
Period 3B	1	.	12	4	1	.	.	*18*
Period 3A	3	.	1	5	.	.	.	*9*
Period 2	3	.	.	.	.	.	.	*3*
Period 1	3	.	.	.	.	.	.	*3*
total	*154*	*55*	*61*	*124*	*10*	*5*	*13*	***422***
objects vs. debris	81 / 73	24 / 31	31 / 30	54 / 70	3 / 7	0 / 5	7 / 6	200 / 222

material sub-assemblage consists of manufacturing debris fragments. It is reasonable to assume therefore that many or most of the finished alabaster objects recovered at Harappa may have been crafted at the site itself. An assortment of these artifacts (including several that were analyzed for this study) is displayed in Figure 10.2 A through C. Although most alabaster artifacts at Harappa have weathered exteriors, cracks and fractures exposing the interior reveal that the material preferred by Harappans tended to be compact, fine-grained and sugary white. A few fragments (but no artifacts) with a pink cast have also been found.

Alabaster objects and debris fragments have been recovered from all major areas of the site (Figure 10.1) and from every chronological phase and sub-phase from Period 1 through Period 3C. Although no examples were found during the very limited excavations of Period 4 and 5 levels, approximately half of the assemblage (n=210) consists of surface finds and so it is possible that some of those artifacts may have originated in Late Harappan strata that were subsequently disturbed by brickrobbers. The great majority (179 of 212 or 85%) of the alabaster artifacts from secure stratified contexts belong to Period 3C. This then is the optimal assemblage with which to examine site-wise synchronic variation in the utilization of alabaster. Next I discuss how that material was distributed across the site during Period 3C. Later in this chapter I examine if resident/craftspeople living in different parts of the site at this time used alabaster from the same sources.

In general, there does not appear to have been a great deal of intra-site variation in the use of alabaster as a raw material during Period 3C. Manufacturing debris is found in those levels on every mound at Harappa as well as from the 3C deposits beneath the Mughal era (16^{th} to 18^{th} centuries AD) caravanserai south of Mound E. People residing and

Figure 10.2: An assortment of alabaster artifacts from Harappa. Those noted with artifact numbers were analyzed for this study.



A. *Clockwise from top-left*: alabaster rings, whorl, ball, bangle fragments, pendent (H94/4999-511), dish fragment, small vessel.



B. Cubical weight made of alabaster from Vats' excavations (#13799).



C. Large alabaster ringstone fragment (H98/7715-9) from Period 3C levels on Mound AB, Trench 42.

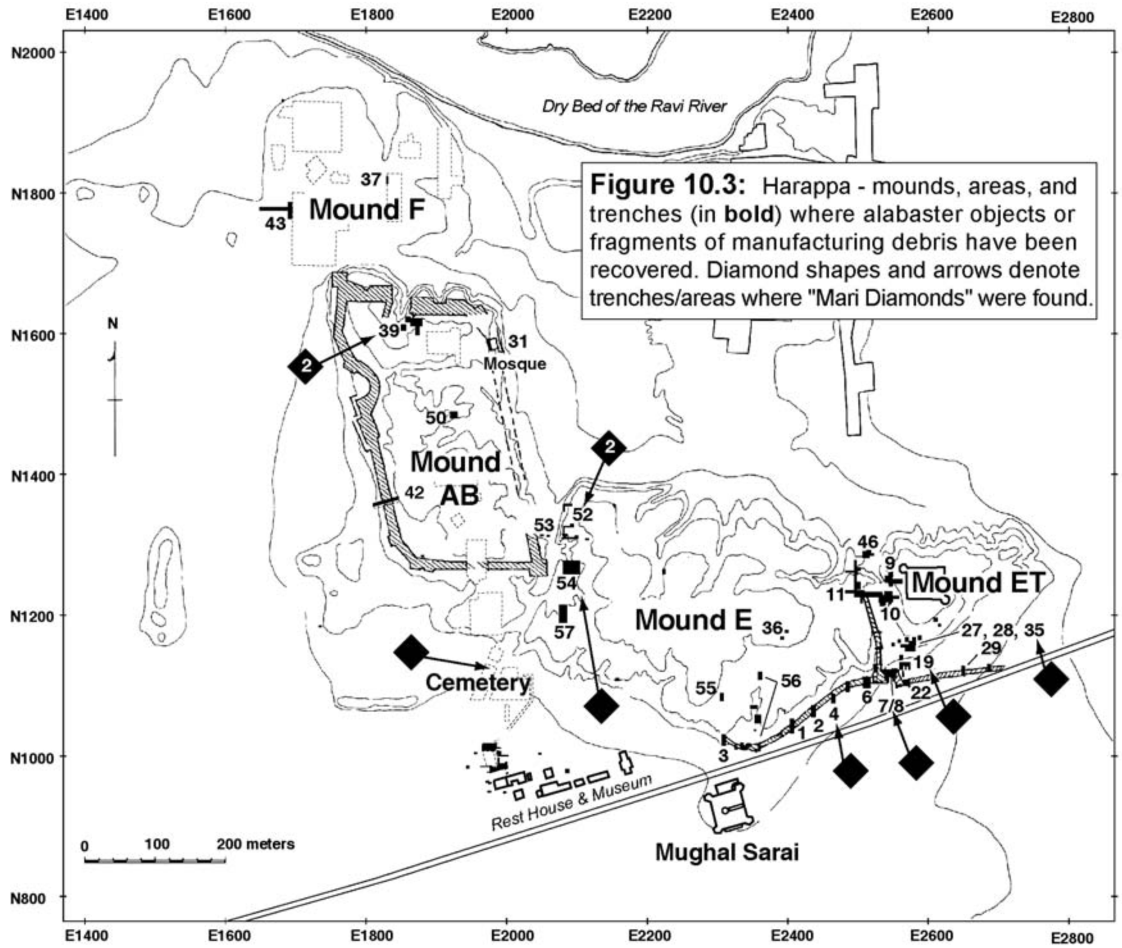


Figure 10.3: Harappa - mounds, areas, and trenches (in **bold**) where alabaster objects or fragments of manufacturing debris have been recovered. Diamond shapes and arrows denote trenches/areas where "Mari Diamonds" were found.

working in different areas of the city were basically making or acquiring the same types of alabaster objects. Certain artifacts, such as the cubical weight pictured in Figure 10.2 B, are exceptionally rare and thus found only in a few locations. More common items, however, such as beads, inlays and vessels tend to be found in most areas of the site. There is one striking exception. Although fairly common (making up around 18% of finished alabaster artifacts), alabaster bangles have only been found on mounds E-ET, which would indicate that residents of those areas were the only ones producing and/or consuming that particular type of item. This may very well be a diachronic pattern. Even though the

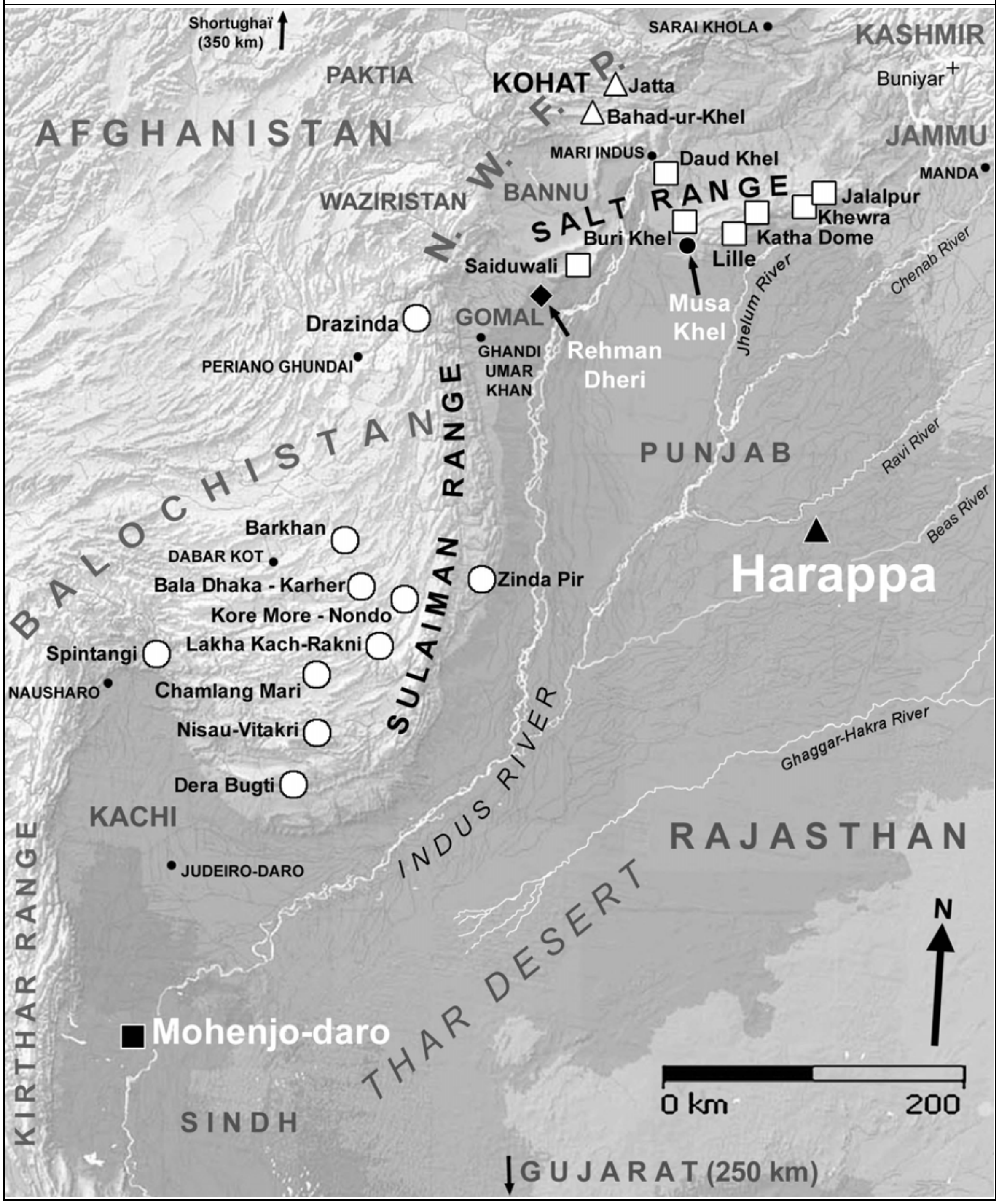
alabaster assemblages for periods prior to 3C are significantly smaller (and thus subject to greater sampling bias), during periods 3A and 3B bangles made of this alabaster are also found only on mounds E-ET.

Twenty-nine alabaster artifacts from Harappa were selected for isotopic analysis (Appendix 10.1). This amounts to approximately a seven percent sample of this material sub-assemblage. The set included artifacts from each of Harappa's habitation mounds and each phase and sub-phase between periods 2 and 3C. Most of those chosen (19 of 29) were non-diagnostic manufacturing debris fragments. The remaining ten samples were taken from both common alabaster objects (bangles and vessels) and important varieties of rare ones (a ringstone and a cubical weight). In the following section I discuss the geologic sources to which these artifacts were compared.

Potential sources of Harappan alabaster

There are extensive deposits of alabaster in several regions surrounding the Indus Basin that would have been directly accessible to Indus Civilization peoples. In this section, I discuss deposits in the three regions that were closest to Harappa – the Salt Range, the Sulaiman Range and Kohat (Figure 10.4). Samples from multiple locations within each of these areas were collected and analyzed for this project. Sources in several other regions are also noted that, although not yet analyzed, are important to be aware of when considering the results of the isotopic studies. Before discussing the potential sources of Harappan alabaster, however, I want to first make it clear that there are certain parts of the Greater Indus region where that material is almost certainly *not* to be found.

Figure 10.4: Regions, sources and sites discussed in this chapter.



Gypsum occurrences that are not alabaster sources

Gypsum is a mineral precipitate that forms in environmental settings (generally arid ones) in which the evaporation of water takes place (Eckhardt 2001; Warren 1989: 14). Those settings may be *terrestrial* (such as inland seas or lakes) or *marine* (typically shallow, marginally restricted oceanic basins). Gypsum is the most common of the sulphate minerals (Deer et al. 1992: 615) and occurrences of some kind or another can be found in most parts of the Greater Indus region (Bender 1995b: 264-265; Wadia 1975: 467). The alabaster variety, however, is much less widespread. Just because a large gypsum deposit is reported to occur in a certain area does not necessarily mean that alabaster are also found there. This is a fact that has sometimes not been adequately recognized when considering the potential sources of that material.

Indus Alluvium/Thar Desert

When outlining the raw material resources available to Indus peoples in the Sindh region, Nayanjot Lahiri noted in the section on “Alabaster” that “thick beds of gypsum are abundant in the Indus alluvium” (Lahiri 1992: 24). Although this is indeed so, the gypsum of terrestrial origin that occurs within the alluvium of the Indus Basin is most definitely *not* of the alabaster variety. Rather, it is either the selenite or the *gypsite* (massive but impure gypsum mixed with sand and clay) varieties that are found in thick beds just below the alluvium (Figure 10.5) in areas like Thar Desert. Such deposits are mined today in the Bahawalpur District of Pakistan (Ahmad 1969: 92) and all throughout west-northwestern Rajasthan (Deb 1952; Geological Survey of India 2001b: 68-70; Jacob et al. 1952).

Figure 10.5: Quaternary gypsite deposit immediately below the desert alluvium, Bikaner district, western Rajasthan.



Western Sindh

It has been suggested that the Harappans of Mohenjo-daro may have obtained alabaster from the nearby Kirthar Range of western Sindh (Lahiri 1992: 24; Pascoe 1931: 679; Ratnagar 2004: 151). This would not have been possible, however, as it is selenite and veins of fibrous gypsum, rather than massive compact alabaster, which occurs in the Tertiary shales of this region (Ahmad 1969: 92). The low grade gypsum of the Kirthar Range is mined today for use in the cement industry (Hunting Survey Corporation 1960: 447; Jafry and Ahmad 1991: 28-30) but would have not at all been suitable for carving the types of artifacts being examined in this chapter. In spite of that, raw material of this kind may still have had value to ancient residents of Sindh. For example:

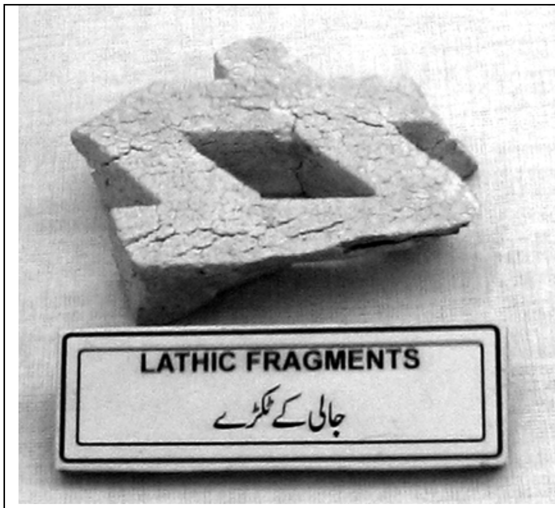


Figure 10.6: Alabaster lattice fragment on display at Mohenjo-daro museum.

Nineteenth century craftsmen in Sindh used gypsum from deposits in the Kirthar Range for "casting lattices and open work for the tops of doors and windows, and for other purposes [where] the partial admission of air is desirable" (Buist 1852: 229). Interestingly, fragments of stone lattices that are thought to have served the same purpose have been found at Mohenjo-daro (Sahni 1931b: 219). Although those objects appear to have been cut or carved from alabaster blocks, it is difficult to tell for certain if this was so because they have heavily weathered exteriors (Figure 10.6). A closer examination of those artifacts might reveal that they were cast from a gypsum plaster instead. This does not mean that alabaster was not used at Mohenjo-daro. On the contrary, many objects that are clearly made of this variety of gypsum have been recovered at the site. It is highly unlikely, however, that the raw stone used to fashion them came from the Kirthar Range. Dr. Massimo Vidale kindly supplied a single small sample from an alabaster vessel fragment found in the area DK at Mohenjo-daro during the surface surveys by the IsMEO-Aachen University project (Pracchia et al. 1985). Analysis of this sample will hopefully allow us to determine what region residents of that site were obtaining that material from.

Gujarat

The Indian state of Gujarat has also been noted as a possible alabaster source for Indus Civilization peoples (Lahiri 1992: 106; Pascoe 1931: 679). Although extensive gypsum deposits do occur in many districts (especially Kutch and Junagadh), a review of the geologic literature indicates that they are not found in the form of alabaster (Desai 1973; Geological Survey of India 2001a: 66-67; Krishnaswamy 1979: 249-250; Sinha 1967: 300-301). Instead it is mostly selenite crystals, such as those that form in the shallow *ranns* (Figure 10.7), which occur there.



Figure 10.7: A mass of selenite crystals from the Little Rann of Kutch, Gujarat

If selenite or gypsite was used to make the mortars, plasters and pastes found at some Indus Civilization sites then those materials could have come from any of the regions discussed above. The alabaster used to make Harappan artifacts, however, could not have. Next we examine several of the regions where high quality alabaster does occur.

The Salt Range

The Salt Range lies on the northern edge of the Punjab Plain, approximately 225 km away from Harappa at its closest point. Beds of massive alabaster gypsum (Figure 10.8) up to 100 meters thick are exposed at various places along the base of these mountains. There has long been a local industry devoted to carving plates and other items from Salt Range alabaster (Wynne 1878: 300; Pascoe 1931: 679; Habib 1986: 13, Map 4B). Geologic

Figure 10.8: Massive alabaster gypsum beds at Saiduwali Nala, Salt Range



samples were acquired from seven sources stretching from the eastern to the western margins of the range (identified with white squares in Figure 10.3). The five easternmost of these deposits occur within the *Salt Range Formation* (Alam and Khan 1982). Although its precise age has been debated (Gee 1945; Ghosh et al. 1951; Shah 1977: 4), today the Salt Range Formation is generally considered to span the late-Precambrian to Cambrian eras (ca. 600 to 500 m.y.a.) (Kazmi 1995c: 66-68; Shah 1980: 8). When referring to deposits associated with this formation I use the term *Infra-Cambrian,* which denotes the period immediately preceding the Cambrian (Palmer 1977). The two westernmost Salt Range alabaster deposits sampled for this study (Daud Khel and Saiduwali Nala) are marine in origin and occur in the *Sakesar Formation* of Eocene age (ca. 55 to 34 m.y.a.) (Kazmi 1995c: 112; Kazmi and Jan 1997: 478).

Alabaster from the Salt Range would have been most directly accessible to Indus Civilization peoples during the Kot Dijian phase (Period 2 at Harappa). In recent years several Kot Dijian sites have been located in the central to eastern part of the range (Dar 2002). The small Early Harappan to Harappan Period settlement of Musa Khel (Dani 1971: 32) lies roughly 15 km southeast of the Buri Khel alabaster deposit. Fragments of alabaster were evident on the site's surface along with other lithic materials from the Salt Range including black chert (Chapter 6), limestone and laterite. Small samples for analysis were taken from two such fragments collected by Dr. Syed Baqri of the Pakistan Museum of Natural History during fieldwork in the area. Alabaster fragments were also observed (and one sampled) on the surface of the Early Harappan Period site of Rehman Dheri (Durrani 1988), which lies just over 30 km southwest of the Saiduwali Nala.

The Sulaiman Range

Two hundred twenty kilometers directly west of Harappa is the north-south running Sulaiman Range. The extensive alabaster deposits located in these mountains (identified with white squares in circles 10.4) are mainly concentrated in the wide southern portion of the range known as the *Sulaiman Lobe*. Zinda Pir, the easternmost of these southern sources, lies in the Dera Ghazi Khan District of Punjab Province. The alabaster found at this deposit and others nearby is described as gray to grayish white in color (Hussain and Mustafa 1970). The remaining Sulaiman Lobe area deposits are situated in Balochistan proper. The geologist W.T. Blanford visited alabaster occurrences in the vicinity of Dera Bugti and described the material there as "perfectly pure white in color, and quite as well adapted for ornamental purposes" (Blanford 1883: 127). Alabaster is also found in the far

north of the Sulaiman Range around Drazinda in the NWFP. All of the Sulaiman deposits are marine evaporites that occur within either the *Baska* or the *Domanda* formation, which are both of Eocene age (Malkani 2000). Mr. M. Sadiq Maklani of the Geological Survey of Pakistan–Quetta generously provided a set of alabaster samples for isotopic analyses from the ten Sulaiman Range locations identified in Figure 10.4.

The alabaster artifacts found at Harappa could easily have been derived from any of the Sulaiman Range sources. Drazinda, the northernmost of the deposits, lies near the natural route between Early Harappan and Harappan Periods sites on the Gomal Plain like Ghandi Umar Khan (Khan et al. 2000) and those of northern Balochistan such as Periano Ghundai (Fairservis 1959: 329). Indus Civilization peoples at sites on the Kachi Plain such as Nausharo (Jarrige 2000) and Judeiro-daro (Flam 1981: 251-53) as well as those living at highland settlements like Dabar Kot (Fairservis 1959: 289) would have been best positioned to access the rich alabaster deposits of Sulaiman lobe region. Although the alabaster found at Zinda Pir does not appear to be the same sugary white variety that was used to make artifacts at Harappa, this source would have nonetheless been the closest and most directly accessible to residents of that site.

Kohat

The Kohat district, NWFP is located directly northwest of the Salt Range. Although the massive gypsum of marine origin that occurs in this region is frequently mixed with clay that gives it a greenish cast, purer beds of white material are often found (Rashid et al. 1965: 4-7; Wynne 1875: 45). Samples of relatively pure alabaster from two deposits – Jatta and Bahad-ur-Khel (identified with white triangles in Figure 10.4), were

kindly provided by Dr. Syed Baqri of the Pakistan Museum of Natural History in Islamabad. Both of those locations occur within the *Jatta Gypsum Formation* of early Eocene age (Bender 1995b: 264; Fatmi 1974: 53-54).

It is important to consider alabaster from the Kohat region in a study such as this even though there would have been closer sources of purer material to Harappa. These deposits lie between 40 and 80 km northeast of the series of Early Harappan sites in the Bannu Basin (Khan et al. 1991a). Some of this material might conceivably have come to Harappa through interaction with related groups in that region.

Other potential alabaster sources

There are several other regions from which the alabaster recovered at Harappa could have been obtained other than, or in addition to, the three discussed above. Although sources in the areas below have not yet been analyzed, it is important to take into account their locations and geologic contexts when later evaluating the results of the isotopic studies. Because some of those areas are located on or near what would have been the northern fringes of the Indus Civilization, several do not fall within the area of Figure 10.4.

Afghanistan

The presence of the Harappan outpost of Shortughaï (Francfort 1984b) in the far north of Afghanistan (not pictured on Figure 10.4) opens the possibility that alabaster from deposits between that area and the Indus Valley may have been brought to Harappa. One potential source of upper Jurassic age (ca. 160 to 145 m.y.a.) is found in the vicinity of Dudkash in Baghlan Province (ESCAP 1995: 58). This occurrence lies near a major route to northern Afghanistan through the Hindu Kush. Other potential sources are found within

Cretaceous formations (ca. 145 to 65 m.y.a.) in the west-northwestern part of the country (Wolfart and Wittekindt 1980: 421) and Eocene-age formations along the eastern border with Pakistan (Ludington et al. 2007: Figure 16).

Hazara (NWFP)

Lying less that 100 km northeast of the Early Harappan site of Sarai Khola (Halim 1972) in the Hazara District, NWFP, are beds of white calcareous gypsum 15 to 200 meters thick that occur within the *Hazara Formation* (Ali et al. 1964: 36-37). Although originally correlated with the Infra-Cambrian Salt Range Formation of the Punjab, radiometric dating has indicted that the Hazara Formation, which has undergone low-grade metamorphism, is probably older (Kazmi 1995c: 72). Of all of the uncharacterized alabaster sources, this one is especially pertinent due to the fact that much of the steatite found at Harappa appears to be coming from this region (see Chapter 7).

Jammu and Kashmir

Alabaster deposits in Jammu and Kashmir are especially pertinent too because, as we shall see in Chapter 12, many of the lead artifacts found at Harappa appear to be coming from these regions. The numerous large deposits of massive “snow white gypsum” that are found across that state are thought to be of Precambrian age (Krishnaswamy 1979: 251-252; Mehta 1957: 61-62; Singh et al. 1994). Harappans interacting with Neolithic peoples in the Kashmir Valley (Saar 1992) via the upper Jhelum River valley would have had access to both lead and alabaster in the vicinity of Buniyar (Middlemiss 1929: 3). Similarly, the residents of the Harappan site of Manda (Joshi and Bala 1982) would have been well positioned to exploit the alabaster (Sinha 1967: 298) and lead deposits of Jammu.

Western Himalayas

Southwest of Jammu and Kashmir (not pictured on Figure 10.4) sporadic occurrences of alabaster can be found in the Carboniferous era formations of the western Himalayas (Wadia 1975: 467). In the Kinnaur District of Himachal Pradesh, alabaster occurs in the *Lipak Formation* (Geological Survey of India 1989a: 29). In the Garhwal region of Uttaranchal, deposits are found in the *Krol Formation* (Chatterjee 1963b: 227). Although no Harappan sites lie within the Himalayas, some have been discovered in the foothills of that range near Chandigarh (IAR 1985-86: 15) and around Ropar (Sharma 1982).

Determining the geologic provenience of Harappan alabaster artifacts

N.H. Gale and others (1988) successfully employed both sulfur isotope analysis and strontium isotope analysis to characterize gypsum deposits in Greece and to assign a geologic provenience to alabaster artifacts from several Mycenaean sites. The same combination of techniques are used in this study to analyze a group of Harappan alabaster artifacts and compare them to a set of geologic materials from potential sources in Pakistan. To begin this section, I provide the geologic background pertaining to alabaster-bearing marine evaporites, relate how the changing isotopic characteristics of seawater makes studies of this kind possible and discuss what might be expected when samples in sets assembled for this study are analyzed. I then present the results of the isotopic analyses and provenience determinations suggested by them – this is done first for each isotopic system alone and then in combination with one another. In the concluding part of this section I discuss diachronic and synchronic patterns of alabaster source usage at Harappa that are evident based on the results of these studies.

Geologic background – Marine evaporites and isotope curves for S and Sr in seawater

The massive beds of alabaster found in the Salt Range, Sulaimans and Kohat are believed to be marine evaporites (Alam and Khan 1982: 3; Bender 1995b: 264). Deposits of this kind form as gypsum precipitates from seawater evaporating in shallow, semi-restricted marine basins (Blatt 1992: 348-350). The alabaster beds of Eocene age that are being considered here would have been originally laid down in the ancient Tethys Sea as it gradually closed between the Indian Subcontinent and the Eurasian Plate beginning around 55 million years ago (Powell 1979: 16). The Infra-Cambrian deposits are perhaps remnants of a similar, but much earlier, process.

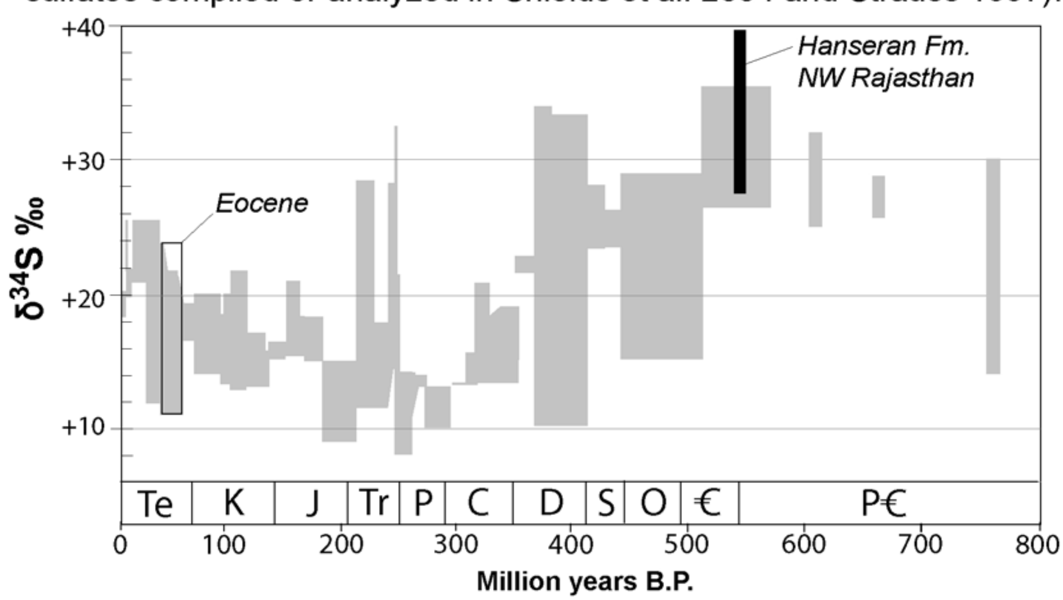
The very different ages of the geologic formations under examination here actually facilitates the effort to determine the geologic provenience of alabaster artifacts from Harappa and other Indus Civilization sites. The reason is that the isotopic compositions of certain elements in the waters of the earth's oceans have undergone considerable changes over time. Sedimentary rocks of marine origin (evaporites like alabaster and carbonates like limestone) contain a record of the sulfur and/or strontium isotope characteristics of seawater during the period of time that they formed (Faure and Mensing 2005: 440-441, 833-835). Analysis of marine evaporites and carbonates of different ages from around the world have enabled geologists to construct isotope "curves" that plot the diachronic changes in the compositions of those elements in seawater. Alabaster artifacts can, with reference to either or both isotope curves, be matched to a geologic formation having analogous isotopic characteristics.

In the two sub-sections to follow, I provide short explanations of the sulfur and strontium isotope curves and an outline of how the alabaster source formations under examination here might expected to plot in relation to them.

The sulfur curve

The element sulfur (S) has four stable isotopes (^{32}S, ^{33}S, ^{34}S, ^{36}S). The ratio of the two most abundant of these (^{32}S and ^{34}S) in a sample is measured with a mass spectrometer. The results are expressed using the notation $\delta^{34}S$ ‰, which represents the per mil (‰) deviation in the $^{34}S/^{32}S$ ratio measured in the sample compared to that measured in the Canyon Diablo Troilite (CDT) meteorite international standard (Eckhardt 2001: 514). Since sulfur isotopes do not undergo substantial fractionation as gypsum is precipitated, the isotopic composition of that element in an alabaster deposit should be essentially the same as the ancient seawater from which it derived (Faure and Mensing 2005: 833).

Figure 10.9: Variation in the isotopic composition of sulfur in seawater through time (gray shaded area represent age uncertains for marine sulfates complied or analyzed in Shields et al. 2004 and Strauss 1997).



The isotopic composition of sulfur in seawater has changed through time and a record of this has gradually been generated through the analysis of marine evaporite sulfate deposits of different ages from around the world (Straus 1997). A representation (the sulfur isotope "curve") of these changes over geologic time can be seen in Figure 10.9. Prior to this study no sulfur isotope analysis had ever been performed on marine evaporites from the three geologic formations under examination here. Nevertheless, based on the sulfur isotope curve we would expect that the Eocene alabaster deposits (and artifacts deriving from them) would have $\delta^{34}S$ ‰ values ranging from approximately +11 to +24 (range noted on Figure 10.9). As for the deposits of Infra-Cambrian age, Harald Strauss and others (2001) analyzed 26 marine sulfate samples from the *Hanseran Formation* of northern Rajasthan, which is generally considered to be analogous to the Salt Range Formation of the Punjab. This formation was not discussed above because it is located at a minimum at a depth of nearly 300 meters below the surface (Strauss et al.'s samples came from drill cores) and therefore could not have been a source of Harappan alabaster. However, Hanseran marine sulfates have $\delta^{34}S$ ‰ values ranging from +27.5 to +39.7 (range noted on Figure 10.9) and so similar values might be expected from Infra-Cambrian Salt Range Formation alabaster deposits and artifacts deriving from them.

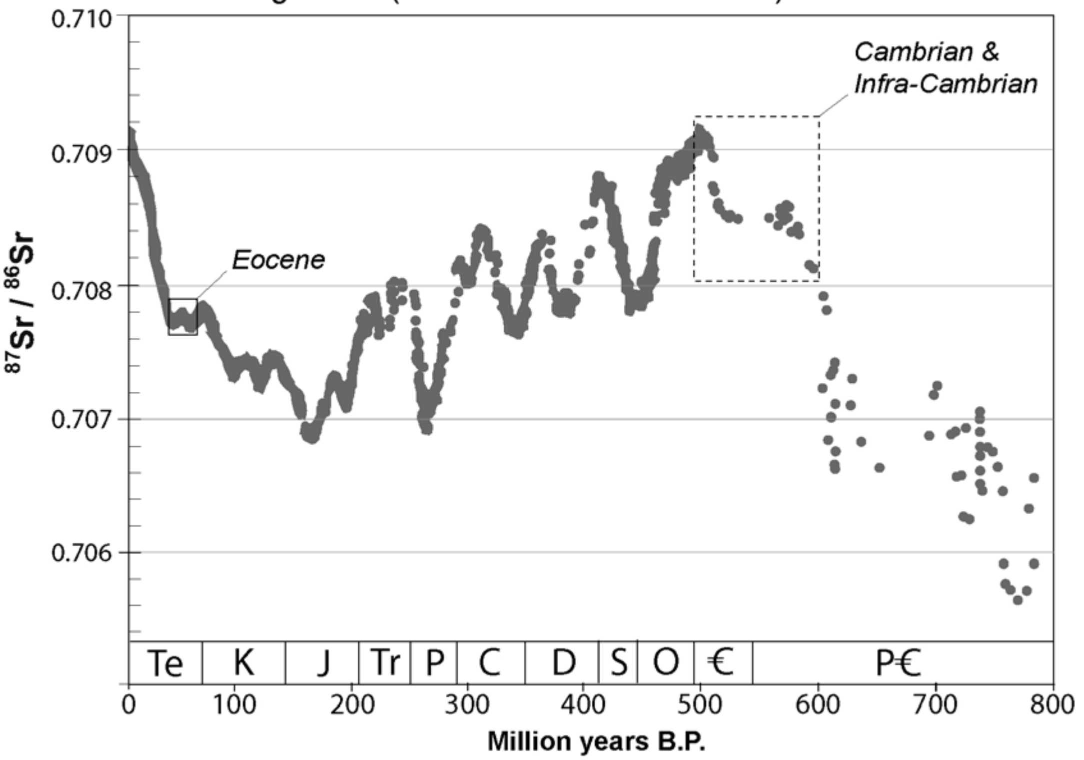
The strontium curve

The element strontium (Sr) also has four stable isotopes (^{84}Sr, ^{86}Sr, ^{87}Sr, ^{88}Sr). In geologic materials ^{87}Sr is augmented over time by the decay of a radioactive isotope of rubidium – ^{87}Rb (Faure and Mensing 2005: 75). However, because the amount of ^{87}Rb in gypsum is extremely low and therefore very little radiogenic ^{87}Sr is generated over time,

the overall Sr isotope composition of an alabaster deposit will essentially be the same (barring any later digenetic changes) as the seawater from which it precipitated (Gale et al. 1988: 59-60). A mass spectrometer is used to measure the ratio of all the strontium isotopes. The ratio of $^{86}Sr/^{88}Sr$, which is constant on the earth, is used to correct the $^{86}Sr/^{87}Sr$ ratio for instrumental mass bias resulting in the very precise determination of the $^{87}Sr/^{86}Sr$ ratio (Dr. Joel Blum, *personal communication* 2005).

Like sulfur, the isotopic composition of strontium in seawater has changed through time. A record of the changes has been generated through the analysis of marine carbonates (fossil shells and limestones) of different ages from around the world (Veizer et al. 1999). A curve depicting the changing strontium isotope characteristics of seawater through the Phanerozoic (Cambrian Period to present) can be seen in Figure 10.10. Although none of the formations being investigated in this study were previously analyzed, the strontium isotope composition of those marine sulfates should be analogous to carbonates formed during the same periods of time. With reference then to the strontium curve published by McArthur and others (2001), the Eocene period alabaster deposits and artifacts deriving from them would be expected to have $^{87}Sr/^{86}Sr$ ratios ranging from approximately 0.7076 to 0.7079 (noted on Figure 10.10). The Sr isotope composition of the oceans prior to the Cambrian Period is not well constrained due to the fact that carbonate rocks from that time are scarce and those that do exist have often been altered (Faure and Mensing 2005: 447-448). Geologic samples and artifacts from Infra-Cambrian deposits could have $^{87}Sr/^{86}Sr$ values similar to those of the Cambrian Period – from approximately 0.7080 to 0.7093 (ibid.: Figure 19.6). It is also possible that those deposits might have even

Figure 10.10: Variation in the isotopic composition of strontium in seawater through time (after McArthur et al. 2001)



higher values. Precambrian marine carbonates in the western Himalayas often have highly radiogenic Sr isotope compositions (from approximately 0.7090 to 0.7323 or even higher) due to isotopic exchange with high $^{87}Sr/^{86}Sr$ silicate rocks during metamorphism (Blum et al. 1998; Jacobson et al. 2002; Sarkar et al. 1996; Singh et al. 1998). Precambrian/Infra-Cambrian evaporate deposits of that region may well have been affected in the same way.

Sulfur and strontium isotope analyses of geologic sources and Harappan artifacts

Two sets of alabaster samples were prepared for sulfur and strontium isotope analysis – a set of archaeological samples and a set of geologic source materials. Details regarding the 33 artifacts comprising the archaeological set (Appendix 10.1) were presented in preceding sections. Twenty-nine samples came from Harappa, two from Musa

Khel and one each from Rehman Dheri and Mohenjo-daro. Both sulfur and strontium isotope analysis are destructive methods and so some material needed to be removed from each artifact. For this reason two-thirds of the samples were chosen because they were unworked, non-diagnostic alabaster debris fragments. Samples that came from finished objects were taken from an already broken or cracked area. Using a fine tungsten carbide drill the weathered surface of an artifact was burred away from a small circular area approximately 2 mm in diameter. The surface material was discarded and then drilling of the freshly exposed area continued until approximately 50 mg of powder was generated. The powder was then divided and placed into two small polyethylene vials for transport to the laboratory. The full set of 33 artifacts was analyzed for sulfur isotope composition but it was only possible to make Sr isotope determinations on 30 of them.

The geologic set consisted of 46 samples – 24 samples from 12 individual deposits in the Sulaiman Mountains, four from two deposits in Kohat and 18 samples from seven deposits in the Salt Range (Appendix 10.2). All of the sampled locations are identified on Figure 10.4. Approximately 200 mg of material was removed from an unweathered, freshly broken surface on each geologic sample and powdered in an agate mortar. The powder was then divided and placed into two small polyethylene vials for transport to the laboratory. The full set of 46 geologic samples was analyzed for sulfur isotope composition but it was only possible to make Sr isotope determinations on 39 of them.

Sulfur isotope analysis and results

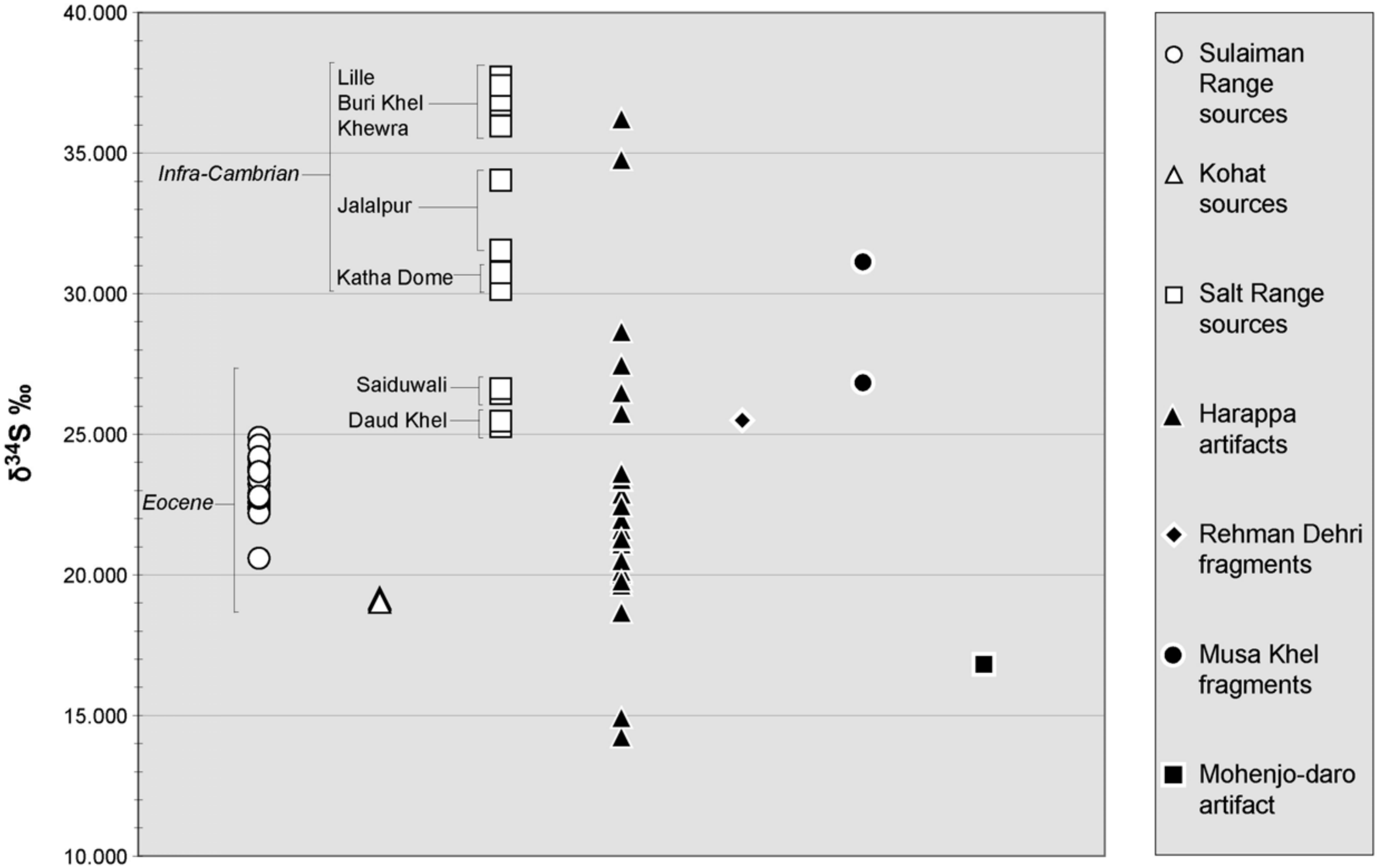
Sulfur isotope analysis of the sample sets was conducted by Dr. Chris Eastoe at the Isotope Geochemistry Laboratory, University of Arizona. Each sample was dissolved in

HCl and then a $BaCl_2$ solution was added to precipitate $BaSO_4$, which as then filtered and dried (Isotope Geochemistry Laboratory 2004). Sulfur dioxide gas was extracted from the $BaSO_4$ by combustion with V_2O_5 (Yanagisawa and Sakai 1983) in a Costech elemental analyzer. From that gas $\delta^{34}S$ values were measured a Finnigan Delta PlusXL continuous-flow gas-ratio mass spectrometer. International sulfur standards OGS-1 and NBS123 were used along with several other sulfide and sulfate materials that have been compared between laboratories. Based on repeated use of internal standards the precision was estimated to be ± 0.15 or better (Chris Eastoe *personal communication* 2004).

The sulfur isotope analysis results for the geologic and archaeological sets are listed in appendices 10.1 and 10.2 and are plotted on Figure 10.11. Samples in the geologic set largely fall where predicted by the sulfur isotope curve for Phanerozoic seawater. The Infra-Cambrian deposits of the Salt Range Formation (noted on the figure) have $\delta^{34}S$ values from +30.15 to +30.69, which is typical of other deposits of that age and places them within the range measured by Strauss and others (2001) for the Hanseran Formation of northern Rajasthan. Most of the Eocene alabaster sources of the Sulaiman Range and Kohat had $\delta^{34}S$ values ranging from +19.02 to +24.89, which would be expected of deposits of that age. The exceptions were the two Eocene deposits of the western part of the Salt Range (Saiduwali and Daud Khel – also noted on the figure), which had slightly higher than expected values (from +25.27 to +26.62).

When archaeological samples are plotted in relation to the geologic sources it appears that alabaster artifacts from Harappa derive from all three regions examined here and as well as, possibly, a fourth unknown source. It seems clear that the two artifacts with

Figure 10.11: Sulfur isotope values for alabaster sources in Pakistan and artifacts from four Harappan sites



the highest $\delta^{34}S$ values came from Infra-Cambrian sources in the eastern part of the Salt Range. Four others are much more closely related sources in the western Salt Range. The two artifacts with $\delta^{34}S$ values below +15.00 would appear to come from an alabaster source other than the three examined here. The bulk of the alabaster artifacts from Harappa, however, have $\delta^{34}S$ values that span the range of variation seen for deposits within the Sulaiman Range and between that region and the Kohat sources. Although some are clearly more analogous to Sulaiman sources than to those in Kohat and vice versa, several plot in an area (approximately +20.00) that falls ambiguously between the two regions.

The artifacts from the other Indus sites plot in both expected and interesting ways. The $\delta^{34}S$ value for the Rehman Dheri fragment not surprisingly falls within the range of the sources closest to that site in the western Salt Range. Although the two fragments analyzed from Musa Khel also plot with Salt Range sources, they appear to probably be from two different deposits. One has a $\delta^{34}S$ ratio value that would indicate that it came from an Eocene source in the western part of the range while the other may have derived from an Infra-Cambrian source farther east. The single sample from Mohenjo-daro does not appear to have come from any of the three regions examined here but may have derived from the same unknown source as the two Harappan samples with the lowest $\delta^{34}S$ values.

Strontium isotope analysis and results

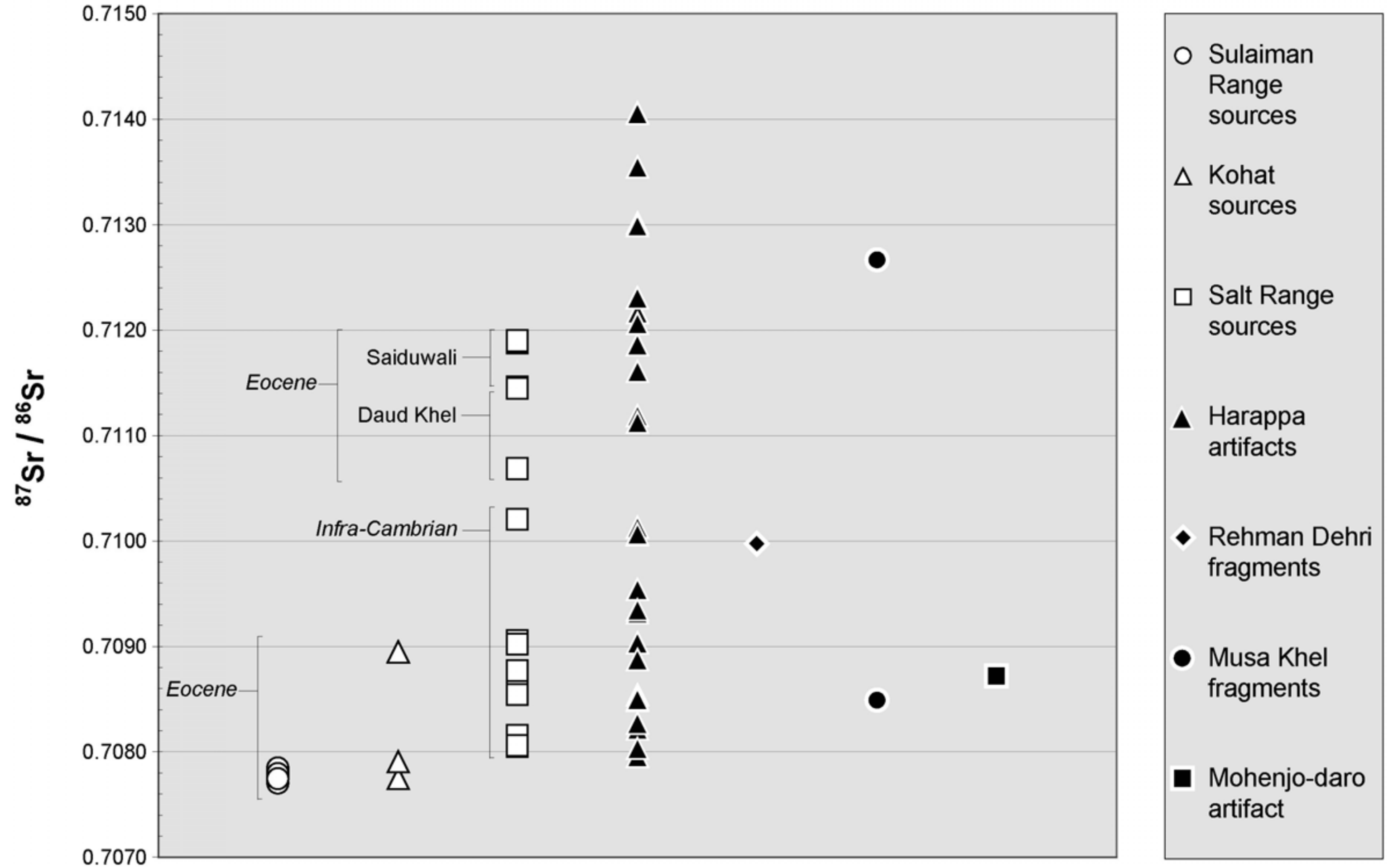
Strontium isotope analysis of the sample sets was conducted by Joel Blum and Andrea Klaue at the Department of Geosciences, University of Michigan–Ann Arbor. Samples were dissolved and strontium was separated from them by cation exchange chromatography following the procedures outlined by Blum and others (1998). $^{87}Sr/^{86}Sr$

ratios were measured on a Finnigan MAT 262 thermal-ionization mass spectrometer (TIMS) and normalized to $^{86}Sr/^{87}Sr = 0.1194$. Replicate analysis of the NIST SRM-987 standard yielded a value of 0.710250 ±0.000014 (2σ, n= 74). The precision of individual analyses was at least ±0.000 020 (2σ).

The results of strontium isotope analysis of the geologic and archaeological sets are listed in appendices 10.1 and 10.2 and are plotted on Figure 10.12. The various geologic sources examined had $^{87}Sr/^{86}Sr$ values that were, for the most part, within the ranges expected for deposits of those ages with regard to the strontium isotope curve. The Infra-Cambrian alabaster deposits of the Salt Range Formation (identified on Figure 10.10) had ratios from 0.708048 to 709053 – a range comparable to those for late Precambrian to Cambrian formations found elsewhere. A single sample of this age from the Jalalpur area had the somewhat high value of 0.710204. Ratios for alabaster occurrences in the Sulaiman Range clustered from 0.707704 to 0.707846 – exactly within the fairly restricted range expected for Eocene marine evaporites. Eocene deposits in Kohat also plot where predicted with the exception of a single sample from the Jatta deposit that has the slightly higher ratio of 0.708949.

When the alabaster sources of the western Salt Range, Saiduwali and Daud Khel (identified with brackets on Figure 10.12), are compared to the strontium isotope curve it becomes evident that they have unusually high $^{87}Sr/^{86}Sr$ ratios (from 0.710686 to 0.711899), especially for deposits of Eocene age but also for typical marine evaporite of Cambrian/Infra-Cambrian age. These same two deposits likewise had higher than expected sulfur isotope values. It was noted above there are some formations of sedimentary marine

Figure 10.12: Strontium isotope values for alabaster sources in Pakistan and artifacts from four Harappan sites



rocks in the western Himalayas that, having been metamorphosed together with high $^{87}Sr/^{86}Sr$ silicate rocks, are enriched with highly radiogenic strontium. The alabaster deposits of the western Salt Range do not appear to have been metamorphosed, however. Whatever the cause(s) for their unusually high isotopic values is eventually determined to be, the Eocene alabaster sources of the western Salt Range are quite clearly distinct from both the Infra-Cambrian deposits to their east and those of the same age in the Sulaiman Range and Kohat.

When the strontium isotope ratios of archaeological samples are plotted in relation to the geologic sources the pattern that emerges is very different and *seemingly* contradictory to the one suggested by the sulfur isotope results. Whereas only six of the 29 samples from Harappa were assigned to Salt Range alabaster sources based on sulfur isotope analysis, 26 samples in the set now fall within or very near the range of variation for Salt Range deposits. The three samples plot higher than any of the geologic sources analyzed here. Due to the single Kohat sample with a high $^{87}Sr/^{86}Sr$ ratio, seven of the archaeological samples are also encompassed within the range of variation for that source region. No samples plot within the very tight strontium isotope range for Eocene deposits in the Sulaiman Range whereas 14 artifacts did when sulfur isotopes were examined.

Artifacts from the other Indus period sites plot in somewhat different ways as well. Although the Rehman Dheri fragment would still be assigned a Salt Range provenience based on its $^{87}Sr/^{86}Sr$ ratio, it now appears more analogous to Infra-Cambrian deposits in the eastern part of that range rather than to the nearest source at Saiduwali. The fragments analyzed from Musa Khel again appear probably to be from two different sources – one

from an Infra-Cambrian deposit and one, perhaps, from the Eocene sources (although it has a ratio that is somewhat higher than those measured from Saiduwali or Daud Khel). The vessel fragment from Mohenjo-daro now falls within the range of both Infra-Cambrian deposits of the Salt Range and the Eocene Deposits of Kohat whereas based on sulfur isotopes it seemed to have been unrelated to any of the three geologic sources.

A handful of archaeological samples have $^{87}Sr/^{86}Sr$ ratios that are higher (in some cases significantly higher) than any of the geologic sources analyzed here. The possibility exists that alabaster artifacts may have been post-depositionally altered in a way that affected the isotopic composition of strontium within them. The waters of the rivers draining the Himalayas are known to have elevated levels of radiogenic strontium due to factors relating to the types of rocks eroding in their upper courses (Singh et al 1998; Sarkar et al. 1996). A water sample taken from the Ravi River upstream from Harappa had a $^{87}Sr/^{86}Sr$ ratio of 0.729120 (Karim and Veizer 2000). Since the introduction of widespread canal irrigation in the late 19th century and early 20th century the water table has risen significantly in this part of the Punjab as well as farther south in Sindh (Michel 1972). Soil salinity had become tremendous problem in these areas and archaeological sites like Harappa and Mohenjo-daro have suffered considerably as moisture moves to the surface through the mounds and artifacts it contains. Porous materials have become impregnated with salt and, presumably, other dissolved elements in the water. As for alabaster artifacts, great care was taken to get below their weathered surfaces and collect material for analysis from the (hopefully) unaltered interiors. The high $^{87}Sr/^{86}Sr$ ratios exhibited by certain samples may very well be a characteristic of the geologic source(s) –

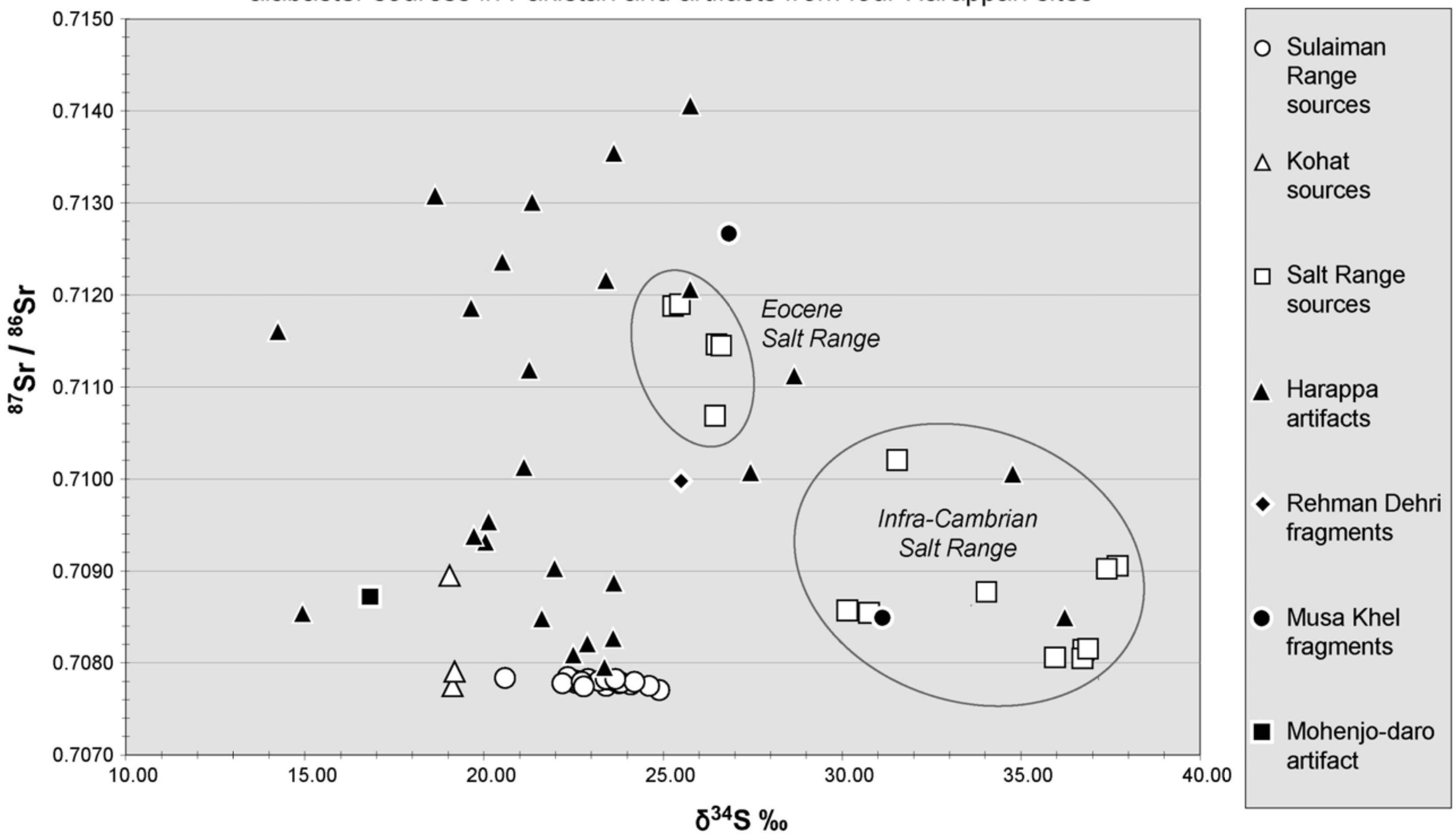
possibly in the western Himalayas (Jammu and Kashmir), they derive from. However, until sources there are analyzed the possibility that alabaster artifacts may have been contaminated by radiogenic strontium from the rivers of the Punjab must be recognized.

Bivariate plotting of the S and Sr analysis data

The seemingly contradictory provenience determinations derived from the sulfur and strontium isotope data might lead one to surmise that either one or both of the methods used were flawed, either in their execution or premise. This is almost certainly not the case, however, as demonstrated by the data resulting from the analyses of the geologic sample set. The isotopic behavior of Phanerozoic seawater is well understood and the assays made here of samples from deposits of marine evaporites of known ages provided values that were, in the great majority of instances, *spot on* with regard to the expected isotopic compositions predicted by *both* the sulfur and strontium curves. Exceptions were probably due to as yet not well understood characteristics of particular geologic formations. Any apparent incongruities between how the archaeological set plotted in relation to the isotope curves are no doubt the result of the geochemical properties of the artifacts themselves. It is important bear in mind that each element alone provides only one dimension with which to examine the possible provenience of archaeological alabaster. Considering sulfur and strontium data *simultaneously* allows a fuller picture of the isotopic variability (or similarity) between geologic formations and artifacts to be generated.

Figure 10.13 is a bivariate plot of the sulfur and strontium isotope data for samples from the geologic and archaeological sets. Strontium values are found on the *y-axis* and sulfur values on the *x-axis*. In this new two-dimensional view the three main geologic

Figure 10.13: Bivariate plot of strontium and sulfur isotope values for alabaster sources in Pakistan and artifacts from four Harappan sites



source regions are even more isotopically distinct from one another than before. The geographically widespread Eocene alabaster deposits of the Sulaiman Range still cluster in a tight a pattern and appear most closely related to sources of the same age in Kohat. Lying in contrast to those deposits and to one another are the two different formations of the Salt Range (circled on Figure 10.13). The high strontium isotope values for Salt Range Eocene alabaster deposits set these clearly apart from all other formations.

The archaeological samples are plotted on Figure 10.13 as black shapes. From this it is evident that at least some of the artifacts from Harappa (triangles) are isotopically analogous, or at least very similar, to the geologic formations examined here. Several fall directly upon or plot within the area encompassed by the geologic sample data points of both the Eocene (Sakesar) and Infra-Cambrian (Salt Range) formations in the Salt Range. Others cluster on and near data points for the Eocene sources in the Sulaiman Range and the Kohat region. Over half of the Harappan samples, however, plot in areas away from these geologic formations. Of those that do, many have high $^{87}Sr/^{86}Sr$ ratios like the Salt Range Sakesar deposits but with slightly lower $\delta^{34}S$ values that cause them to fall in a loose cluster above and to the left of that formation. It is difficult to say if these seemingly similar archaeological fragments actually represent a single source formation or multiple ones. If we use the Infra-Cambrian formation of the Salt Range as a model then it is evident that individual deposits of a single formation can spread widely. Conversely, the isotopic ranges of the geographically widespread Eocene sources of the Sulaimans and Kohat are much more constrained. It is important to point out that only five data points presently exist for the Sakesar Formation deposits, which lie adjacent to this cluster. The

possibility exists that future analyses of geologic source material (from the same deposits and additional ones) might eventually enlarge the isotopic boundaries the Sakesar marine evaporates to encompass some of those ungrouped artifacts. On the other hand, it is also very possible that the raw material for those artifacts may have come from one of the potential sources discussed above that has not yet been analyzed. The most obvious candidates would be those alabaster deposits in parts of the western Himalayas where marine carbonates are known to have similarly high levels of radiogenic strontium.

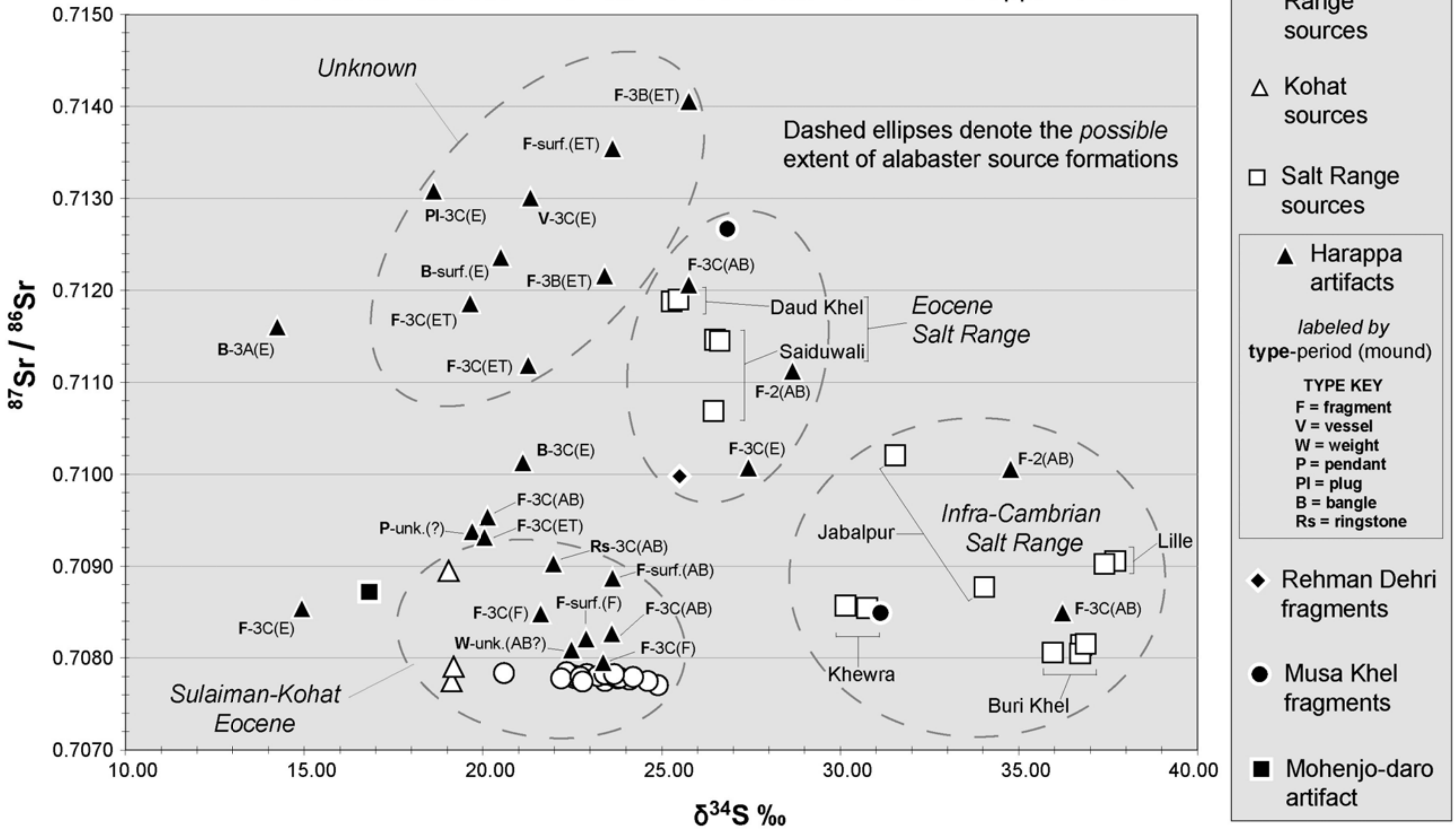
The way in which the alabaster samples from the other prehistoric sites fall on the bivariate plot is informative. Once again the two fragments from the site of Musa Khel (black circles) appear to be from different Salt Range formations – one clearly comes from an Infra-Cambrian deposit and the other falls quite close to the Eocene age sources. The latter fragment, along with the one from Rehman Dheri (black diamond), provide a good indication of how the isotopic boundaries of Salt Range Eocene alabaster deposits *might* expand when additional analyses are undertaken of geologic samples from the Sakesar Formation. The alabaster vessel fragment from Mohenjo-daro (black square) along with a single fragment from Harappa stand apart due to their low sulfur and strontium isotope values. Although these two samples could be from a deposit related to the Eocene source formations of the Sulaiman Range or Kohat, they are clearly not from the Salt Range. Certain trade items such as chlorite vessels were brought to Indus cities like Mohenjo-daro from regions far beyond the Indus Valley (Kohl 1975, 1979). It is therefore possible that these alabaster artifacts, and perhaps some others, originated from sources much more distant than the ones discussed in this chapter.

Chronological and spatial interpretation of alabaster provenience determinations

It has been demonstrated that at least some of the alabaster artifacts from Harappa probably came from the geologic sources analyzed for this study. The provenience of other artifacts remains unclear. Nevertheless, much can still be learned about acquisition and use of alabaster at Harappa by examining the patterns derived from the isotopic data in tandem with the temporal and spatial contexts of the archaeological samples.

Figure 10.14 is a version of the bivariate plot of sulfur and strontium isotope data that has been modified to help illustrate some of the points that I discuss in this sub-section. On it, the individual deposits in the Salt Range are noted and archaeological samples from Harappa are labeled with a three part code that denotes artifact type (the type key is on the figure), period and mound of origin. For example, an artifact coded "F-3C(AB)" is an alabaster fragment recovered from Period 3C levels on Mound AB. The dashed ellipses that have been added to the figure represent the *possible* extent (isotopic boundaries) of geologic sources. These are admittedly speculative and do not represent statically generated confidence intervals. The Infra-Cambrian source area was the only one that was demarcated based on geologic samples alone. The dashed ellipse marking the Eocene Salt Range deposits was drawn to encompass archaeological samples from the sites of Rehman Dheri and Musa Khel, which presumably come from that formation. The Sulaiman-Kohat ellipse is based partly on geologic samples from those regions and partly on archaeological samples that cluster on or nearby them. A final ellipse was drawn to encompass the loose cluster of archaeological samples that plot above and to the left of the Salt Range Eocene deposits.

Figure 10.14: Labeled bivariate plot of strontium and sulfur isotope values for alabaster sources in Pakistan and artifacts from four Harappan sites



With reference to Figure 10.14, I begin by examining alabaster source utilization through time. To date only six alabaster artifacts have been recovered from levels earlier than Period 3 at Harappa – three from Period 1 and three from Period 2. Of these, two fragments from Period 2 were analyzed for this study and both appear to have come from Salt Range sources – one from an Eocene deposit and the other from an Infra-Cambrian deposit. Albeit the sample size is very small, the utilization of alabaster from sources north of Harappa is very much in line with the acquisition patterns being observed for other rock and mineral resources during the Early Harappan Period such as grindingstone (Chapter 5), chert (Chapter 6), steatite (Chapter 7) and lead (upcoming - Chapter 12). Note on the figure that there are also alabaster fragments from Period 3C with isotopic values analogous to deposits in the Salt Range. This provides further evidence (along with steatite, vesuvianite-grossular and lead) that Harappans continued to utilize materials from this northern zone well into the urban phase.

Evidence has been presented throughout this dissertation that indicates the emergence of fully urban lifeways at Harappa coincided with an increase in both the number of rock and mineral varieties being brought to the site and the overall number of source regions around the Greater Indus from which such materials were being obtained. This trend towards diversification is yet again apparent with regard to the alabaster acquisition networks in which Harappans were involved during Period 3. Although only a few artifacts coming from periods 3A (n=1) and 3B (n=2) have been analyzed, most of them have isotopic characteristics that clearly set them apart from Salt Range deposits, which suggests that new sources had come into use. Sulfur and strontium isotope data

exists for 16 alabaster artifacts from Period 3C levels. It appears from the way these artifacts plot on the figure that, in addition to the two different formations of the Salt Range (discussed above), raw material from at least two other sources (and possibly several more) was being brought to Harappa at this time. One of these new source regions appears to have been the Eocene deposits to the west and northwest of Harappa. Although I have demarcated this cluster with a single ellipse, some of the artifacts in it closely group with Sulaiman Range deposits while others appear more like Kohat material. It is highly probable that the smaller clusters of artifacts within the ellipse represent materials from multiple deposits across these geologically related regions. Another apparent source (or sources) is represented by the widely spaced cluster of artifacts with high $^{87}Sr/^{86}Sr$ ratios labeled "unknown." This is the group that may or may not be related to the Eocene formation of the Salt Range. There are also scattered cases where artifacts seemingly plot away from or between the main clusters. These may represent materials from still other sources or they may just be outliers of either the known or proposed geologic formations. Despite the fact that the geologic provenience of these and many other archaeological samples remains unclear, it is certainly well evident that during Period 3C Harappans were utilizing alabaster from at least three or four different source regions.

Lastly, we turn to synchronic variation of alabaster source usage at Harappa. It was stated toward the beginning of this chapter that, aside from the fact that residents of Mound E were apparently the only ones creating and/or consuming alabaster bangles, there does not appear to have been a great deal of intra-site variation in terms of the utilization of this material during Period 3C. Interesting patterns that seem to suggest otherwise, however,

become evident when artifacts from this period are examined in relation to their possible geologic provenience. It would appear that the only Harappans using alabaster from the "unknown" source formation were those living and working on mounds E and ET. Residents of those areas also obtained some of that material from most other available sources with the exception of the Salt Range Infra-Cambrian deposits. People on Mound AB at this time utilized material from both Salt Range formations as well as the Sulaiman-Kohat sources. The Harappans of Mound F appear to have gotten their alabaster exclusively from deposits located in the Sulaiman Range.

Although these results seem to suggest that there might have been genuine differences in alabaster acquisition between peoples dwelling/working in the various habiation at Harappa, caution is advisd because of the very small samples sizes involved in this study (only two to five artifacts from each of the major mounds have been analyzed for this period). Many more analyses of artifacts from the different parts of the site will eventually need to be conducted in order to determine if these patterns are valid.

Characterization of Mari "Diamonds" from Harappa

A number of small (≈ 1 cm) pink-colored quartz crystals have been recovered at Harappa that could potentially provide an added dimension to this study of Harappan alabaster acquisition networks. If not for the highly distinctive bi-pyramidal shape of these artifacts (three examples can be seen in Figure 10.15 A) they would have simply been recorded as examples of common rose quartz. However, crystals of this exact description are known to occur *within* massive gypsum (Figure 10.15 B) found at certain locations in the Salt Range. The best known occurrences are located on either side of the Indus River at

Figure 10.15: Mari "Diamonds" – artifacts, sources and analyses



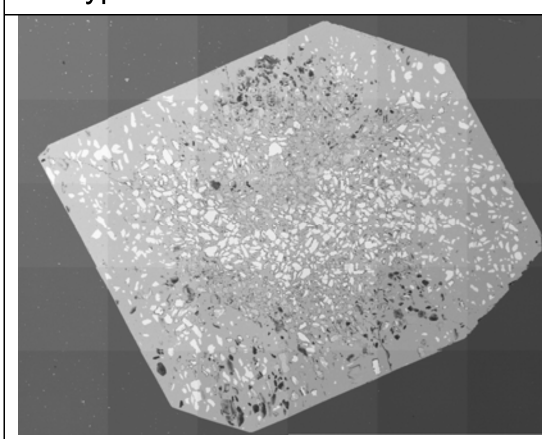
A. Three examples of unusual pink-colored bi-pyramidal quartz crystals recovered at Harappa.



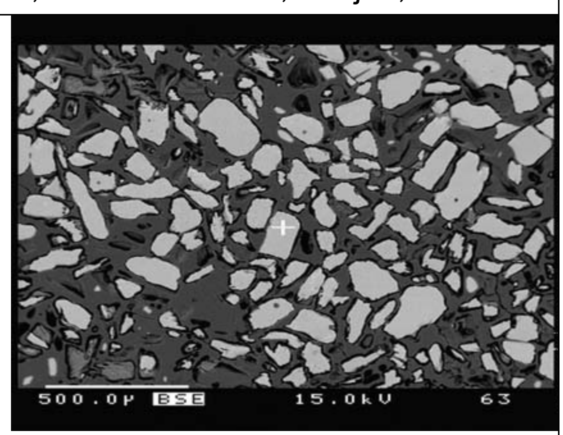
B. Quartz crystals in gypsum-anhydrite matrix from Mari Indus.



C. Gypsum and salt marls at Mari Indus, District Mianwali, Punjab, Pakistan



D. Back scatter electron image of a section of an inclusion-filled Mari "Diamond" from Harappa.



E. Detail of anhydrite inclusions in Mari "Diamond."

the point where it passes through the Salt Range and onto the Punjab Plain (Punjab Government 1907: 203). Local residents have long been known to search through the gypsum and salt marls of "Diamond Hill" near the village of Mari Indus (Figure 10.15 C) for these unusually shaped quartz crystals, or Mari "Diamonds," which they fashioned into necklaces (Alam and Khan 1982: 8; Wynne 1878: 300). In the site report for Mohenjo-daro, Sir Edwin Pascoe specifically mentions this source in the section outlining possible sources of rock crystal (Pascoe 1931: 678). It is unclear, however, if any quartz artifacts having this unusual shape were ever encountered at Mohenjo-daro or if the pink bi-pyramidal quartz crystals found at Harappa actually came from the Salt Range. Dr. Albert Verchere (cited in Government of the Punjab 1883-84: 18) noted bi-pyramidal quartz crystals in the brecciated gypsum of the Waziristan Hills. In the stone bazaar of Peshawar, I examined examples of similar crystals embedded in a gypsum matrix that were attributed to Afghanistan's Paktia Province, which lies adjacent to Waziristan. Bi-pyramidal crystals called "diamond quartz" are also known from the Karnur area of Tamil Nadu in southern India (Karnath 2000: 251 and Figure 10.7a). The nearest occurrences to Harappa, however, are those in the Salt Range. If it could be shown that the Harappan examples are indeed Mari "Diamonds," then that would be an excellent second line of evidence indicating the exploitation of alabaster deposits in that region during the prehistoric period.

In addition to their unusual shape, petrographic studies (Chhibber 1944; Lenk-Chevitch 1955; Holland 1891) have revealed that Mari "Diamonds" from the Salt Range contain minute inclusions of *anhydrite* – calcium sulfate ($CaSO_4$) – which is basically gypsum without the water component. It is highly unusual to find this mineral within the

structure of a crystal and can certainly be taken as indicative of its formation within a gypsum, alabaster or anhydrite deposit. No quartz crystals, bi-pyramidal or otherwise, have ever been reported to occur in either the Balochistan or Kohat alabaster deposits and, as far as I have been able to determine, quartz crystals (of any shape) containing inclusions of anhydrite inclusions do not occur in other geologic environments in South Asia.

In order to determine if the small pink-colored bi-pyramidal quartz crystals from Harappa are indeed Mari "Diamonds," two examples were selected for characterization using electron microprobe analysis (refer to the section on EMPA in Chapter 2 for details regarding this technique). Back-scattered electron imaging (Figure 10.15 D & E) revealed that both of the crystals examined were filled with inclusions ranging from approximately 20 to 200 µm (microns) in size. Scans with the microprobe's energy dispersive spectrometer (EDS) indicated that these inclusions were indeed composed of anhydrite. These results strongly support the conclusion that crystals at Harappa with this unique visual appearance are indeed Mari "Diamonds" from the central Salt Range.

To date, ten Mari "Diamonds" have been recovered at Harappa (Appendix 10.3) and none of them appear to have been intentionally modified in any way. It is possible that these examples were transported to the site within the matrix of a piece of raw alabaster and subsequently discarded. Small pieces of pink colored quartz are occasionally found that may represent examples that broke as craftsmen attempted to work them. However, most of these pieces are too fragmentary to determination if they were bi-pyramidal like Mari "Diamonds" and so have not been given that classification until such time as they can be characterized in greater detail using EMPA.

Although few artifacts of this type exist, they have been found across the site from Mound ET in the east to the north side of Mound AB (refer back to Figure 10.3 for locations). One example was found in the Harappa Period dump that covers part of the cemetery area. Most of the Mari "Diamonds" from secure stratigraphic contexts come from Period 3B or 3C levels, although two that may date as early as Period 2 have been found in mixed deposits on Mound AB. The finds from the later levels provide a small but important piece of evidence suggesting that materials from alabaster deposits of the central Salt Range were still being brought to Harappa during the latter half of the urban phase.

Chapter conclusion

The combination of sulfur and strontium isotope analysis has proven to be an effective method with which to identify the probable geologic sources of Harappan alabaster artifacts. Even though the provenience of some samples in the archaeological set remains ambiguous and there are several important potential geologic sources left to be characterized, many new insights have been gained into the acquisition and utilization of alabaster in northwestern South Asia during the third millennium BC.

Kot Diji Phase (Period 2) residents of Harappa used alabaster from both the Eocene and Infra-Cambrian age deposits of the Salt Range. They may very well have obtained this material through trade with their Early Harappan contemporaries at sites like Rehman Dheri and Musa Khel, which lie in the vicinity of those mountains and have alabaster fragments on their surfaces isotopically analogous to sources found there. At Musa Khel, as at Harappa, materials from each of the two Salt Range alabaster formations were present. This, taken together with the evidence that black chert identical to that found in

Period 2 levels at Harappa may have also been brought to Musa Khel from nearby sources (Chapter 6), suggests that the site was an important gathering place or staging area for rock and mineral resources collected from across this region. Its location near the base of one of the major passes through the Salt Range further strengthens this possibility.

New sources of alabaster began to be used at Harappa as society there and elsewhere in the Indus Valley took on a decidedly urbanized character beginning in Period 3. Exploitation of older sources did not cease however. On the contrary, they continued to be used well into the urban phase as evidenced by the presence through Period 3C of both Salt Range alabaster and Mari "Diamonds." Still, most of the alabaster used by urban phase residents of Harappan seems to have come from either the Eocene deposits west and northwest of the site in the Sulaiman Range and Kohat regions or from the as yet unidentified source(s) characterized by highly radiogenic strontium. That source(s) more than likely lies somewhere in the western Himalayas (possibly Jammu and Kashmir) although there is a chance that it could also be related to Eocene deposits in the Salt Range. A few artifacts from Harappa and the vessel fragment from Mohenjo-daro suggest that consumers in the Indus Valley at this time had at least limited access to still other sources.

The results of this study also suggested that some intra-site differences *may* have existed at Harappa in terms of the acquisition and utilization of alabaster. For example, all alabaster analyzed from Mound F comes from deposits in the Sulaiman Range. Craftspeople on Mound AB also utilized Sulaiman alabaster as well as raw material from both of the Salt Range formations. A slightly different pattern of acquisition and production was left by people residing in the eastern half of the site. Residents of the

adjoined mounds E and ET were apparently the only ones at the site producing and consuming alabaster bangles. In addition they seem to have been the sole group with either access to or the desire to work material from the "unknown" alabaster source with unusually high levels of radiogenic strontium. Similar site-wise variations in raw material procurement and/or utilization have been observed between the major mounded areas at Harappa for grindingstone (Chapter 5), vesuvianite-grossular garnet (Chapter 9) and "Ernestite" (Chapter 4 and Appendix 4.5).

The amount of alabaster manufacturing debris that is evident at Harappa may not reflect the scale of production there as well as a material like agate does for the bead making industry. The reason is that the waste produced by working a material like agate is generally of little further use and so all or most of it remains in the archaeological record as evidence of that activity. Gypsum, on the other hand, had a very broad range of uses in the ancient world (Levey 1958). Consequently, a large portion of the debris generated during the making of alabaster objects at Harappa may have been collected and used for other purposes that are less detectable archaeologically, thus leaving a much diminished record of production. Even if this was the case, however, the ubiquitous presence of this material across the site and throughout its chronological sequence, when combined with the evidence that multiple sources were at times exploited to meet supply needs, strongly suggests that alabaster working was one of the more important lithic industries at Harappa.

Lastly, although it impossible to know for certain in what sizes Harappans typically transported raw alabaster from the sources identified here, it is stands to reason that the pieces of stone brought to the site for creating objects such as dishes and bowls were

significantly larger and heavier than the thin-walled finished products that are found. The best piece of evidence currently available is the large ringstone fragment pictured in Figure 10.2 C, which weighs approximately two kilograms. When that artifact was complete it probably weighed no less than 10 kg. It is therefore possible to state that Harappans (or the people who were supplying them) were capable of transporting raw alabaster of at least that size from certain source areas. With regard to this particular artifact that source appears to have been west of Harappa in the Sulaiman Range. Pab sandstone grindingstones of that size and greater came from the Sulaiman Range (Chapter 5) and so it is not at all surprising that other materials were also transported in bulk sizes from that region.

In the next chapter, I identify and trace the acquisition networks for several distinctive varieties of limestone that were used to make, among other things, the largest type of stone objects found at Harappa – ringstones.

Chapter 11

Limestone acquisition networks

Chapter 11 – Limestone acquisition networks

Chapter introduction – Limestone

There are five main macroscopically distinct types of limestone in Harappa's rock and mineral assemblage. These types were mostly used to create objects larger than are typically found at the site. Some of those objects are "ringstones" and other big pieces of carved stone that probably had some architectural and/or ritual-symbolic purpose. Large pieces of limestone were also evidently acquired for utilitarian purposes, such as the blocks probably used as sewer drain covers. Like grindingstone (Chapter 5), the heavy and unwieldy nature of comparatively large stone artifacts such as these makes examining them especially useful for detecting subtle and sometimes not so subtle, changes in the ability and/or desire of ancient peoples to acquire difficult-to-transport heavy stone resources. In addition, the likelihood that some of these large objects were important ritual or prestige-related items provides another dimension with which to examine the ways in which social power was expressed through the consumption and display of stone.

Using ICP-AES supplemented by ICP-MS and INAA, I compare 107 limestone artifacts from Harappa (roughly half of the site's assemblage for this material variety) to 160 geologic samples collected from multiple locations in six limestone-bearing geologic formations in Pakistan and India. It is revealed that, mainly during Period 3C, Harappans acquired expensive-to-transport large limestone objects from multiple sources, some as far away at Kutch in Gujarat. This chapter commences with a discussion of the kinds of large limestone artifacts found at Harappa and other Indus cities. I then provide details on the material properties and possible geologic sources of the five different limestone types most

commonly used to make large objects at Harappa. The primary that was used method to characterize artifacts and geologic source material is new and somewhat experimental (Law and Burton 2006b). I therefore present the provenience results in the same exploratory, step-by-step manner in which the data were obtained and evaluated. The implications that the provenience determinations made here have on our understanding of long-distance trade, inter-regional interaction and changing expressions of prestige and power at Harappa is discussed in the summary section that concludes this chapter. Regions, sites and sources mentioned in this chapter are identified in Figures 11.1 through 11.3.

Large limestone artifacts at Harappa and other Indus cities

As discussed in Chapter 1 (p. 56), around 95% of the artifacts in Harappa's rock and mineral assemblage are small in size and light in weight. Grindingstones composed of sandstone-quartzite or igneous and metamorphic rocks make up most of the five percent or so of large objects that weigh more than one kilogram. After grindingstones, however, almost all remaining artifacts in the bulk size/weight category are composed of limestone.

Ring-shaped objects made of various kinds of stone have been found at many prehistoric sites in northwestern South Asia. Large-sized (some weighing over 100 kg) ringstones made of limestone, however, are a category of artifact that seems to be exclusive to Indus cities (Dales 1984). The function(s) of these objects is unclear. They have been interpreted variously as Shivite "yoni" stones (Marshall 1931d: 58-60), astronomical "calendar stones" (Maula 1984) and ceremonial stones associated with cultic tree-worship (During-Caspers and Nieskens 1992: 94). Mackay's suggestion (1938: 597) that the ringstones found at Mohenjo-daro may have been elements of composite columns made of

Figure 11.1: Sites and regions discussed in this chapter.

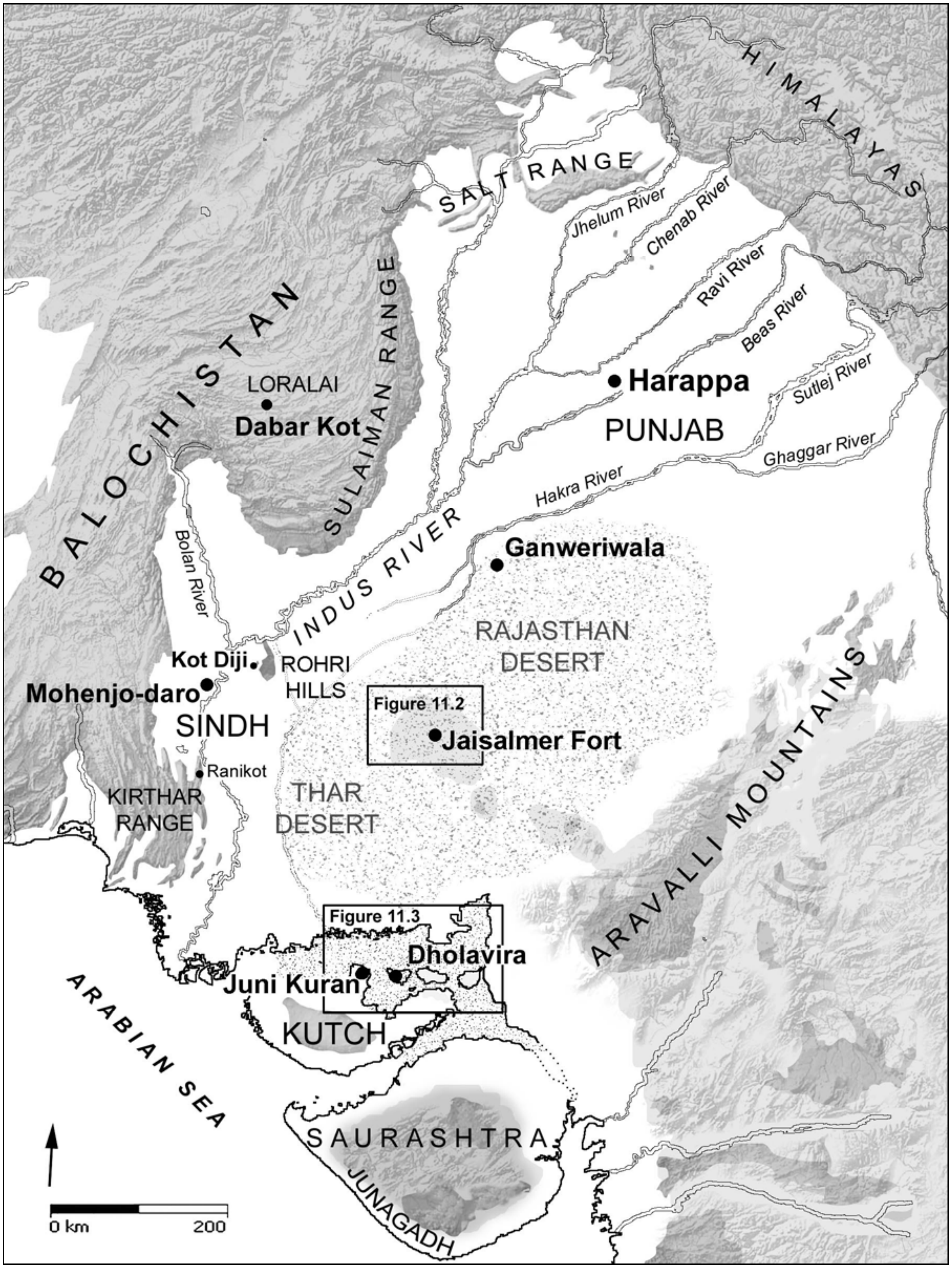


Figure 11.2: Limestone outcrops in the vicinity of Jaisalmer Fort, western Rajasthan that were sampled for this study.

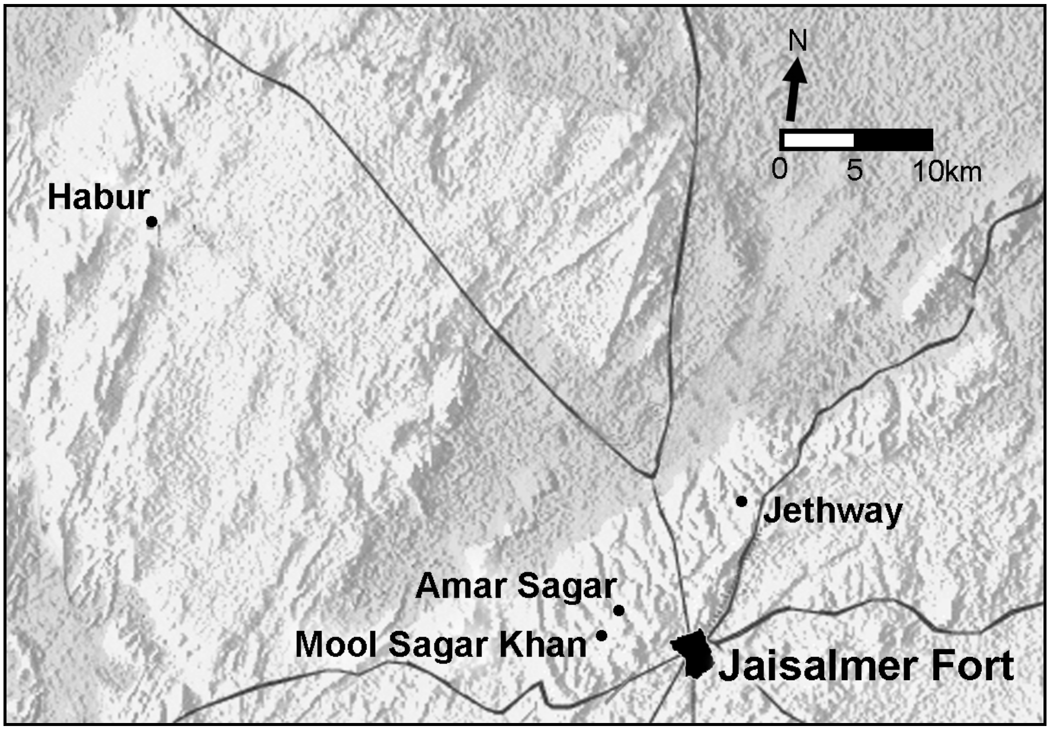
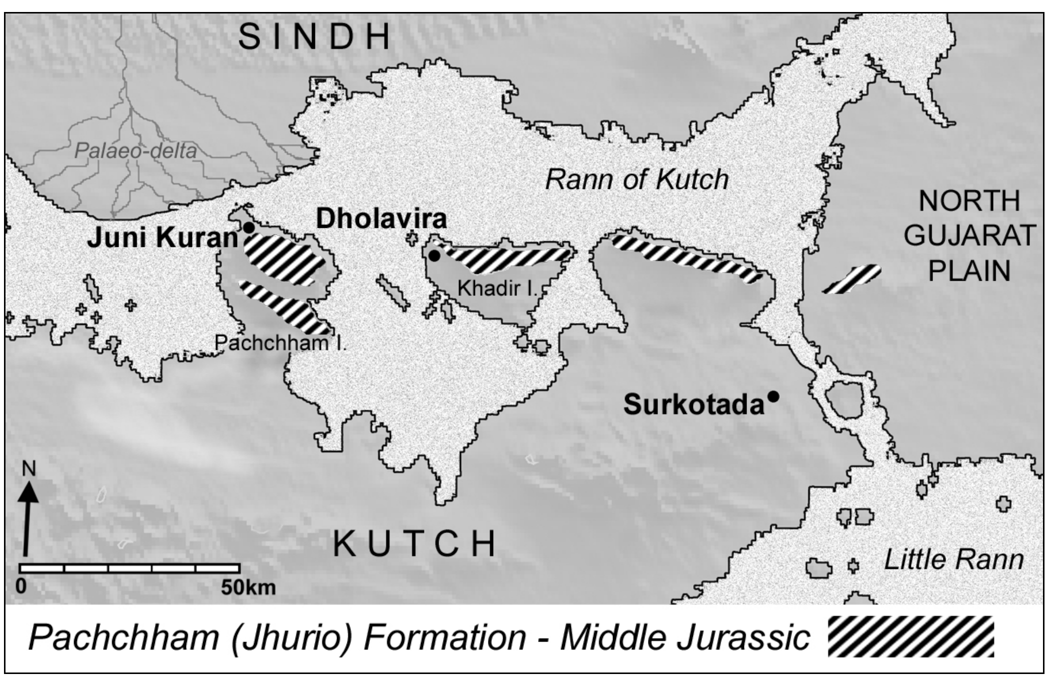


Figure 11.3: Sites and pertinent limestone outcrops in northern Kutch.



stone and wood is probably the closest to being correct. In the southern gateway of the citadel at Dholavira, complete ringstones have been found in positions that indeed suggest that they may have been column (pillar) bases (Bisht 1989b).

The styles in which large ringstones were carved and types of limestone that they were made from differed from site to site. The "typical" large ringstone at Harappa has an undulating (or wavy) top and base with a large central hole and is often composed of a light yellow micritic (microcrystalline) limestone (Figure 11.4 A). Ringstones found at Mohenjo-daro are usually made of a cream-colored micritic limestone and have a flat top and base with a large central hole (Figure 11.4 B). Examples from Dholavira are made from a sandy-textured yellow and reddish-brown banded limestone, have flat tops and bases with small central holes and can have either concave or convex midsections (Figure 11.11 A).

Large conical objects, frequently composed of limestone, have been found at Harappa, Mohenjo-daro and Dholavira. Such artifacts are usually interpreted as "phallic emblems" or *lingams* (Marshall 1931d: 58-61) although some may have actually been grindingstones (Mackay 1938: 407) or doorstoppers (R.S. Bisht *personal communication* 2007). Two large examples stored in the Harappa Museum's Reserve Collections (Figure 11.5 A) may be the ones mentioned by M.S. Vats in a footnote (1940: 51) as having been recovered in excavations trenches in the central to southern part of Mound AB.

Large limestone blocks may have occasionally been used at Harappa for more utilitarian purposes such as drain covers, just as they were at Mohenjo-daro (Figure 11.6 left). Several fragmentary (Figure 11.6 right) and a few complete blocks of a type of limestone similar to the kind used at Mohenjo-daro have been recovered.

Figure 11.4: Large ringstones from Harappa and Mohenjo-daro



A. Large wavy ringstones at Harappa nearby the tomb of Baba Noor Shah (Naugaza).



B. Flat-topped micritic limestone ringstones from Mohenjo-daro

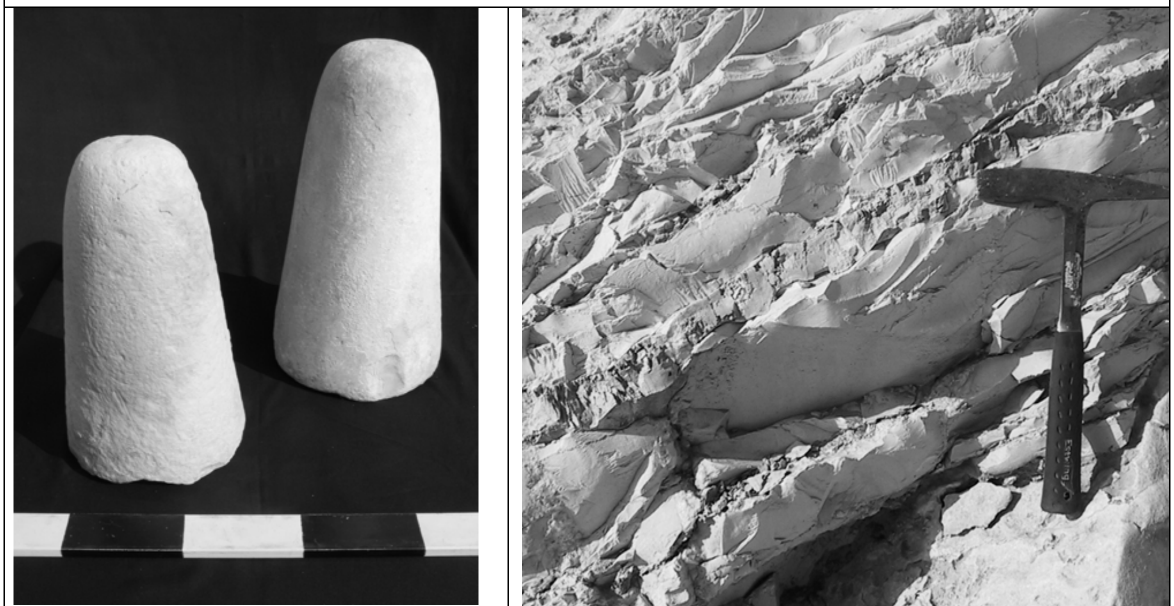


C. Flat-topped banded limestone ringstone from Mohenjo-daro



D. Large banded flat-topped ringstones (HLS-007 and HLS-008) from Harappa.

Figure 11.5: White limestone cones from Harappa and a white limestone source in Balochistan



A. White limestone conical objects from Harappa (10 cm increments on scale).

B. White porcelaneous Parh limestone in the Loralai District, Balochistan

Figure 11.6: *Left* – Micritic limestone drain covers at Mohenjo-daro. *Right* – Possible drain cover (top) and micritic limestone fragments from Harappa.



Figure 11. 7: Some of the unusually shaped stone fragments (architectural elements?) from the north side of Mound AB



A. Facade (?) fragment with raised concentric grooves.

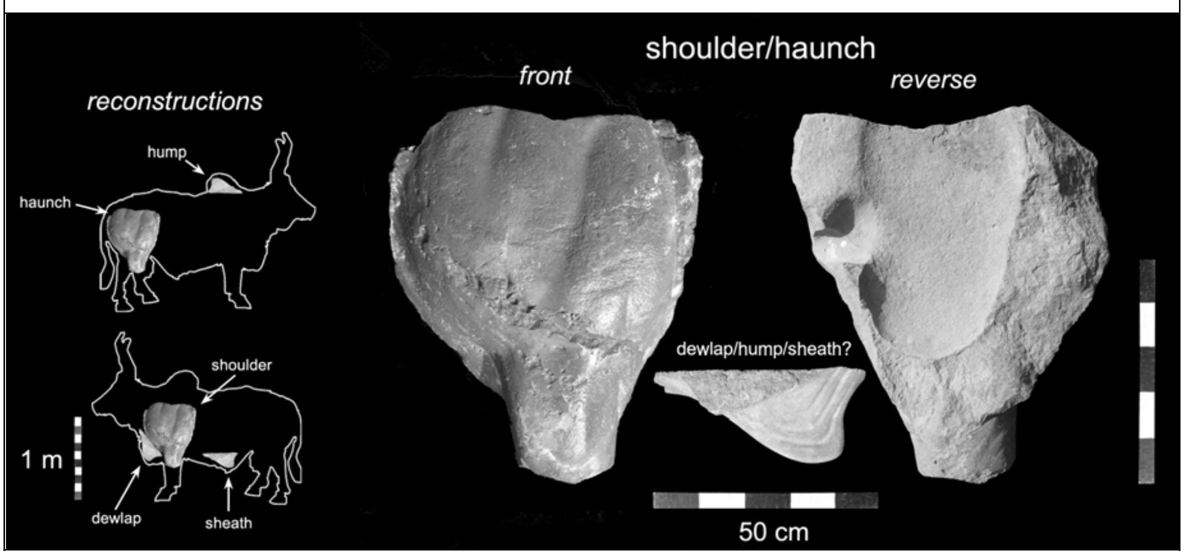
B. Reverse side of a fragment with carved sockets.

C. Polished rectangular block with drilled hole.

Red, gray and yellow sandy limestones were used at Harappa to carve what appear to be architectural elements. During the excavations of the 1920s, a series of large stone artifacts, including cones and ringstones, were excavated by R.B.D.R. Sahni in Trench “B” on the northeast corner of Mound AB in levels that would have been equivalent to Period 3C because of their association with pointed-base goblets (Vats 1940: 139). A great many of the objects were fragmentary blocks that on one or more sides were polished or carved with decorative grooves (Figure 11.7 A). On the reverse sides of these pieces holes or sockets were sometimes found that would seem to indicate they were meant to be inserted or affixed onto something as if part a molding or a composite stone facade (Figure11.7 B & C). More examples of these unusually shaped fragments, most of which are composed of a sandy limestone or calcareous sandstone, were recovered in Period 3C levels in the same general area (Trench 39) during the 1998 season of the HARP (Meadow et al 1998: 6). As far as I can tell this particular kind of stone object is unique to Harappa, to this area of the site and to this period. All in all, their presence suggests that a structure or structures heavily adorned with stone may have existed in this area during the latter part of the urban phase.

In January of 2004, Prof. Mark Kenoyer and I had the opportunity examine the aforementioned large stone artifacts from Sahni's excavations on the northeast corner of Mound AB, which are stored in the Harappa Museum's Reserve Collection. Among them is an object (Figure 11.8) that is recorded as a "block of gray sandstone roughly resembling a (?) tortoise-shell" (Vats 1940: 139, Plate CVXII 8). After closer examination it appears that it is actually a fragment from a life-sized composite statue/frieze of a large bovid, most likely a bull. It is difficult to tell with certainty whether or not the piece represents the front shoulder portion of the animal or its haunch (I have shown the two possible reconstructions on the right hand side of Figure 11.8) but the shaft of a leg descending from the muscled body is clearly evident. On the reverse side of this shoulder/haunch piece is a large bowl-like depression indicating that it may have been re-used for a period of time as a grindingstone (Kenoyer *personal communication* 2004).

Figure 11. 8: Fragments belonging to composite sculpture of a bovid (bull?) from R.B.D.R. Sahni's excavations on the northeast corner of Mound AB



During this same field season, a workman at the site brought to Prof. Kenoyer's attention a sculpture fragment that he had found in the modern cemetery at the base of Mound AB, directly below where Sahni's excavations had been. This fragment, which was made of the same type of gray-colored stone that I call "gray sandy limestone" (discussed below), may represent a bull's dewlap, a hump or sheath (see possible reconstructions on Figure 11.8). Also, in the 1940 report but not in the Reserve Collection is another object from Sahni's excavations on the northeast corner of Mound AB, which is described as a "hoof" (Vats 1940: 141, Plate LXXXIII 36). At around 17 cm in length, this "hoof" (if that's what it is) would be roughly proportionate with the other two pieces.

Of course, it cannot be certain that these fragments are all part of the same sculpture/frieze. No information on the context of the dewlap/hump is available and, although they were found in the same general area, the "hoof" and the shoulder/haunch were recovered in different "stratum" (note that the "stratum" and "depth" recording system used during the 1920s excavations makes it difficult to accurately judge the chronological relationships). Although the position of Sahni's excavation trench suggests that they could come from late Period 3C levels, it is Prof. Kenoyer's opinion that (Kenoyer *in press* a) the pieces date to the Mauryan Period (ca. 4^{th} to 2^{nd} century BC) or slightly earlier. Regardless of thier age, the shoulder/haunch piece alone, at 126 kg, is one of the largest and heaviest stone objects (made of limestone or otherwise) ever found at Harappa. Only one ringstone from the site is heavier.

In the following section, I examine the major types of limestones used to make the various large objects discussed above as well as the potential sources for those types.

Types of limestone used at Harappa and their potential sources

Limestone is a highly variable rock both compositionally and visually. It is, in addition, widely available in most of the geologic formations surrounding the Indus Basin. For these reasons it may seem that identifying the sources from which Harappans obtained this material variety would be highly problematic, if not impossible. However, as in the case of grindingstones (Chapter 5), a close examination of limestone artifacts indicates that several distinctive material *types* exist within the overall assemblage. Macroscopically some of these types seem to correspond with stone found in a limited number of geologic formations around the Greater Indus region. Although it may not be possible without extensive sampling and analysis to discover the precise location (as in a specific quarry) that one of these distinctive limestones types came from, geochemical characterization can enable us to state, with a reasonable degree of confidence, which of two or more geologic formations an artifact more than likely was derived from.

In this section I discuss the major types and potential sources of the limestones used to make large objects at Harappa. Approximately 200 limestone artifacts have been tabulated since excavation by the HARP recommenced in 1986 and many more from past excavations are stored in the Harappa Museum's Reserve Collection. The types that are discussed in this section were defined based on macroscopic properties of the artifacts alone. Details regarding the texture and color (as determined using a Munsell Rock Color Chart) of all of the archaeological samples analyzed in this study are provided in Appendix 11.1. For that appendix the macroscopic type names were shortened and noted in uppercase letters - BANDED, YELLOW, GRAY, MICRITIC and WHITE.

Sandy limestones

The material for a great many of the artifacts that I examine in this chapter was recorded, not incorrectly, as "sandstone." As noted in Chapter 4, limestones are sedimentary rocks that are highly variable compositionally. The geological convention is to call a rock limestone if it is composed of 50% or more calcium carbonate (Rapp 2002: 250). Some types have so much silica that they are essentially a mixture of sandstone and limestone (Lambert 1997: 24). Although no whole rock analyses have been conducted to determine the exact proportions of the major mineral constituents of any of the geological or archaeological samples examined this chapter, I can say that the materials comprising the datasets are quite variable. Within both Harappa's "limestone" artifact assemblage and the various individual geologic formations that I visited and sampled for this portion of my dissertation, there are a full range of materials that could be called sandstones, "calcareous" sandstones (containing a high amount of calcium carbonate), "siliceous" limestones (containing a high amount of silica) or just plain limestones. For the sake of simplicity, I refer to all of those with moderate to high silica contents as "sandy limestones."

Banded yellow-brown and yellow-brown sandy limestone (BANDED)

In January of 2004, two large ringstones stored in the reserve collection of the Harappa Museum were briefly removed for conservation purposes (Figure 11.4 D). The smaller of the two ringstones may be the one that the excavator M.S. Vats described as coming from the center of the old Harappa Police Station on Mound ET (1940: 140 & Plate CXVII, 3). Although we do not currently know where on the site the larger one was found, they are both clearly of Harappan design – albeit apparently not a local one. Vats

Figure 11.9: Three types of sandy limestone artifacts from Harappa.


A. Banded sandy limestone fragments.



B. Small banded sandy limestone ringstone or mace-head (H86/05-13).


C. Bright yellow-red sandy limestone ringstone fragments from Harappa.



D. A very “Jaisalmer-like” bright yellow-red sandy limestone (HLS-044).


E. Gray-red sandy limestone fragments.


F. Broken gray sandy limestone ringstone (HLS-066).

noted (ibid.) that the ringstone found at the old Police Station lacked the wavy undulations typical of those found at Harappa but was similar in style to the flat-topped ones found at Mohenjo-daro (Sahni 1931a: 191). While cleaning these artifacts it was possible to closely examine the material from which they were made, which was a sandy textured limestone that had yellowish orange with pale brown to red-brown banding or patches. At Mohenjo-daro one ringstone exists (Figure 11.4 C) that is carved in an identical in style and material as the two banded ringstones from Harappa. It is possible that these unusual flat-topped ringstones were created at that city and then brought to Harappa. However, in addition to the ringstones, fragments and smaller artifacts made of the same "banded yellow-brown" sandy limestone have been recovered (Figure 11.9 A & B). If the fragments represent manufacturing debris (they may actually just be broken pieces of larger artifacts) then it could mean that this type of limestone was brought to the site in large unmodified blocks.

Bright yellow-red sandy limestone (YELLOW)

Another type of limestone at Harappa with a sandy texture has a distinctive bright yellow, at times "golden" color and is frequently mottled with red or pink patches. Harappans created objects of all descriptions from this stone including wavy ringstones and architectural elements (Figure 11.9 C & D). When past and present excavators at Mohenjo-daro and Harappa encountered artifacts made of this sandy limestone they used the term "Jaisalmer" stone to describe them (Marshall 1931c: 31; Vats 1940: 140, 358; Meadow et al 1998: 6). Jaisalmer, in western Rajasthan, is known as the "Golden City" because of the heavy use of bright yellow-red limestone/sandstone in the architecture there

(Figure 11.10 A). Whether or not Harappan "Jaisalmer" stone actually comes from the Jaisalmer region, however, remains to be determined.

Gray-red sandy limestone (GRAY)

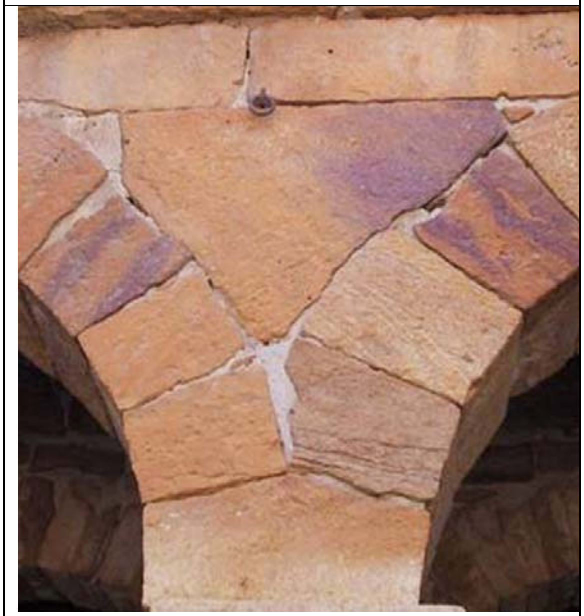
The final major type of sandy limestone used at Harappa is gray to grayish-red in color and can occasionally have an almost crystalline texture. This type was used to make architectural elements, wavy ringstones and the sculpture pieces (Figure 11.8; Figure 11.9 E & F). Of the three sandy limestones this one appears to have the highest silica content. It is moderately fossiliferous and is probably more appropriately described as "calcareous" sandstone.

Three possible source formations for the sandy limestones used at Harappa

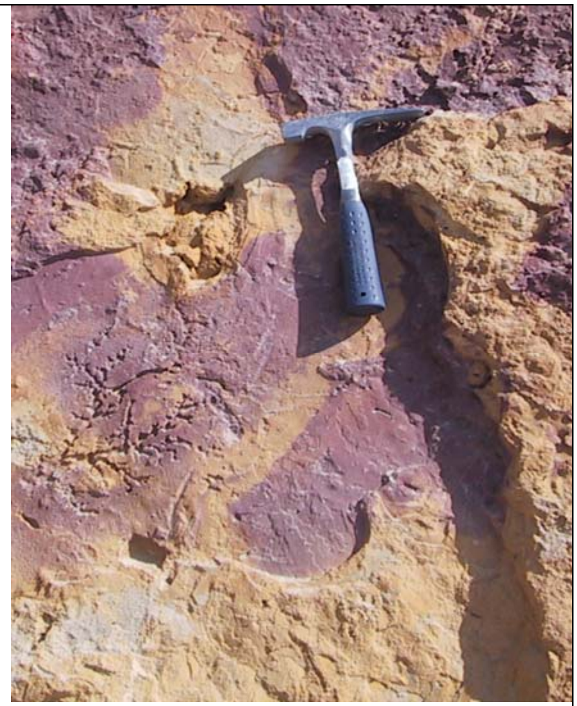
A review of the geologic literature indicates that there are few formations surrounding the Indus Basin where sandy limestone with these precise textural and visual characteristics can be found, either separately or together. Although extensive bodies of limestone exist in the Himalayas, the Salt Range and regions west of the basin, the material found in those tends largely to be fine grained, micritic or porcelaneous in texture. There are three regions on the margins of the lower Indus Basin, however, where visually varied deposits of sandy textured limestones (or calcareous sandstones) are known to occur.

The closet of the regions is an area of low broad plateaus that rise out of the desert sands of western Rajasthan, India (Figure 11.2). The limestone deposits of Jurassic age that occur in this region have long been exploited as a source decorative building stone (Agrawal et. al. 1999: 22-24). Here, 450 km south-southwest of Harappa, sits the city of Jaisalmer, famous for its golden-hued architecture (Figure 11.10 A). The quarries

Figure 11.10: Types of limestone found in the Jaisalmer region.



A. The bright yellow-red sandy limestone masonry at the “golden” fort of Jaisalmer, western Rajasthan



B. Bright yellow-red sandy limestone at Mool Sagar Khan, 5.5 west of Jaisalmer Fort.



C. Banded sandy limestone at Jethway, 10km north of Jaisalmer Fort.

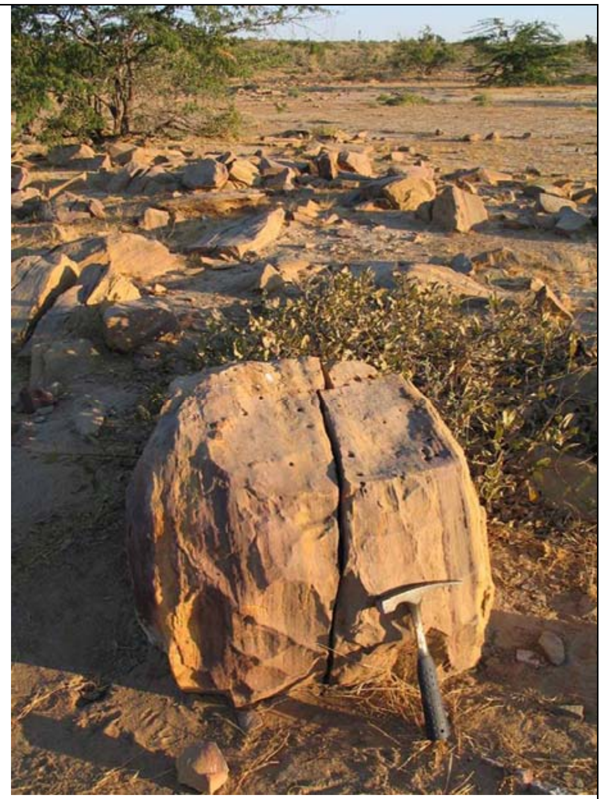


D. Gray, yellow and red sandy limestone at near Habur, 45km northwest of Jaisalmer Fort.

Figure 11.11: Pachchham limestone from Khadir Island and Pachchham Island, Kutch.



A. Ringstones (column bases) from Dholavira on display in the National Museum, New Delhi.



B. Discarded ringstone rough-out at the ancient banded limestone quarry 3 km north of Dholavira, Khadir Island, Kutch.



C. Red-brown and thin yellow banded type of sandy limestone at the Harappan quarry near Dholavira.



D. Blocks of yellow and gray types of sandy limestone in a village wall near the Harappan site of Juni Kuran, Pachchham Island, Kutch.

that were exploited for much of the distinctive bright yellow-red sandy limestone used to build the city are found within 10 km at Mool Sagar Khan (Figure 11.10 B) and nearby Amar Sagar. Similar material is also found north of the city near Jethway along with a banded yellow-brown type (Figure 11.10 C) that moderately resembles the banded type found at Harappa. Beginning around 45 km west of Jaisalmer Fort at Habur are limestone outcrops that, although sandy in texture, are more fossiliferous and crystalline. Pockets of gray to gray-red material are found here (Figure 11.10 D), along with yellow-red types, which are somewhat similar in appearance to the gray sandy artifacts from Harappa – especially the ringstone fragments.

W.T. Blanford noted in his geological survey of western Sindh that stone from the Ranikot beds of the Kirthar Range "closely resembles the very beautiful Jurassic limestone procured at Jaisalmer" (1879: 194). This second potential source formation lies approximately 700 km southwest of Harappa but only around 100 km from Mohenjo-daro.

A third potential source region for sandy limestone is located nearly 800 km south of Harappa. The Pachchham limestone formation of Jurassic age (Fuersich 2001) is exposed on several islands located within the intermittent inland sea known at the Great Rann of Kutch (Figure 11.3). The southernmost Indus city of Dholavira is located on one of these islands called Khadir (Bisht 1991). Unlike at other Indus cities, stone is used here not only for the gateway ringstones that so resemble the two flat-topped ones from Harappa, but also for the city's walls, stairs, houses, drains, wells and other public works. Much of this stone seems to have come from a Harappan period quarry located three kilometers directly north of the site (R.S. Bisht 2003 *personal communication*). The

Pachchham limestone at this point (and in nearby Limdiwali Tari) is sandy textured and has yellow-brown with reddish-brown bands – again, visually identical to the two ringstones from Harappa. Most significantly for this study are what appear to be ringstone 'blanks' that were discarded during the roughout process (note the large crack splitting the ringstone blank in Figure 11.11 B). Several of these have been found within the kilometer long quarrying area. Note also the visual similarity between large waste flakes left behind at the ancient quarry (Figure 11.11 C) and some of the banded sandy limestone fragments from Harappa (Figure 11.9 A bottom left).

Around 45 km west-northwest of Dholavira across the Rann on Pachchham Island lies the Harappan period site of Juni Kuran. Recently excavated by the Archaeological Survey of India (Pramanik 2005), this site appears much like a smaller version of Dholavira, with a rectangular stone perimeter wall and a "citadel" with gateways in which ringstones have been found. The Pachchham limestone in this part of Kutch tends to have a more sandy crystalline texture and, in addition to yellow brown material, there are gray types (Figure 11.11 D) similar in appearance to gray sandy limestone artifacts.

Micritic and white chalky-porcelaneous limestones (MICRITIC and WHITE)

Microcrystalline and fine-grained limestones of various colors ranging from white to dark yellow-brown were used by Harappans to create many different kinds of objects both large and small. The two main kinds of large-sized micritic limestone artifacts – wavy ringstones (Figure 11.4 A) and drain covers (Figure 11.6 *right*), have already been mentioned in preceding sections. The potential sources of this type of limestone stone are far too numerous to be mentioned in detail. The closest and most accessible geologic

formations containing limestone of this type would have been either those of Eocene age found in the Sulaiman Range or the Permian to early Eocene formations of the Salt Range (Bender 1995b: Table 9.4). The Eocene Rohri Hills in Sindh are another possible source.

Only a small number of limestone artifacts over all have been found at Harappa that are made of chalky white to porcelaneous white limestone. The two large conical objects described above and a half dozen or so fragments (Figure 11.5 A & B) represent most of that sub-assemblage. Limestone formations of this kind, although still widespread, are comparatively less common than the micritic ones. In Balochistan, porcelaneous Parh limestone (Ahmad 1969: 104) can be found from the Loralai District in the north part of the state to the Kirthar Range in the south. Chalky white limestone is found in the upper part of Laki Formation of southern Sindh (Jafry and Ahmad 1991; Fatmi and Khan 1998).

Section summary

Many of the large objects created or acquired by residents of Harappa were composed of limestone. The principal types they used were sandy limestone (banded yellow-brown, bright yellow-red and gray-red), micritic limestone (of varying shades) and white chalky-porcelaneous limestone. Identifying the regional source(s) of the latter two might prove difficult due to the wide geographic extent across which limestones of those types occur. However it may be possible to determine which of two potential geologic formations is the most probable source of the sandy limestone artifacts found at the site. The Jaisalmer formation is by far the closer of the two possible source areas to Harappa. However, the nearest Indus Civilization sites to that formation lay approximately 150 km away across the desert in either Cholistan (Mughal 1997) or the Thar region of eastern

Sindh (Mallah 2000). On the other hand, although Kutch is almost twice as far away from Harappa, there is indisputable evidence that the ancient Indus peoples living in that region exploited the local limestone of the Pachchham formation. Transporting heavy pieces of stone (the larger of the two flat-topped banded ringstones found at Harappa weighs 135 kg) from Kutch to the Punjab, however, would have certainly been a difficult and costly undertaking. In the following section I attempt to shed light on this problem through comparative elemental analyses of limestone artifacts and geologic source materials.

Geologic provenience studies of Harappan limestone artifacts

Past studies, choice of instrumentation and presentation of data

In recent years there have been numerous geologic provenience studies of limestone artifacts, sculpture or building materials. Some studies have employed atomic absorption spectrometry (AAS) in combination with carbon and oxygen isotope analysis (DeVito et al. 2004). Others researchers have made petrographic thin-sections of limestone samples and matched them to geologic formations of the same age through palaeontological analysis of microfossils in the stone (Capedri et al. 2001). Studies using INAA have been particularly successful in characterizing quarries and sourcing limestone sculpture and building stone in Western Europe (Holmes and Harbottle 2003). Most recently, a geologic provenience study of limestone artifacts and sources using electron paramagnetic resonance (EPR) spectroscopy yielded promising results (Polikreti et al. 2004).

Each of the above methods is destructive at some level and has its own particular strengths and weaknesses. For this study of Harappan limestone artifacts and their potential sources, the choice to use the inductively-coupled plasma spectrometers as the

primary tools for analysis was largely based on access to those instruments at the LARCH and the experience of Dr. James Burton in using them. To my knowledge no one prior to this time had used ICP-MS or ICP-AES to source archaeological limestone and so the process of analysis was very much exploratory and experimental. I have therefore chosen to present the results of this study in a way that illustrates the step-by-step sequence in which the archaeological and geologic datasets were analyzed and the results evaluated.

The archaeological and geologic limestone datasets

This study began as a small pilot project with a limited number of samples. The materials analyzed for the pilot study, or what I am calling the <u>initial</u> dataset, consisted of six samples of archaeological limestone from Harappa (HLS-001 through HLS-006), 15 geologic samples from two locations near Jaisalmer (JLS-001 through JLS-015) and 15 geologic samples from the Harappan Period quarry near Dholavira (DLS-001 through DLS-015) generously provided to me by that site's excavator, Dr. R.S. Bisht of the Archaeological Survey of India. Five of the archaeological samples were examples of sandy limestones that resembled the geologic source materials. One sample [HLS-003], was a micritic limestone and was clearly very different than any of the other artifacts or geologic samples. All artifacts are coded using an "HLS" number that corresponds to their official HARP "year/lot-record" numbers listed in the second column of Appendix 11.1

After the very promising results of the pilot study (discussed below), the number of archaeological and geologic samples was substantially increased. I refer to this as the <u>expanded</u> sample set. The archaeological set grew to include 107 limestone artifacts. Only very small pieces (≈ .005 g) were required for analysis. Half of the samples were taken

from flakes or non-descript fragments. The other half were obtained during the examination and cleaning of objects, such as the ringstones from the Harappa Museum's Reserve Collection. In all cases small chips were carefully removed from already damaged areas (note the broken bottom portion of the smaller ringstone in Figure 11.4 D).

The expanded geologic set grew to include 60 sandy limestone samples from the four locations visited in the Jaisalmer region of Rajasthan along with 65 samples from three areas within the Pachchham Formation of Kutch. Also added to the geologic set were 25 samples of micritic limestone from the Rohri Hills of central Sindh, three samples of chalky white Parh limestone from the Loralai District of Balochistan, five samples chalky limestone from the Junagadh District of Gujarat and two samples of fine sandy yellow limestone from the Kirthar Range near Ranikot in western Sindh. Specifics as to why limestones from these other sources were added to the set are discussed in more detail below. Descriptions of the all samples comprising the archaeological and geologic datasets along with the results and supporting data related to the various analyses conducted on them can be found in appendices 11.1 through 11.7.

Sample preparation, analysis and data evaluation

Three separate techniques were used to characterize either all or a portion of the archaeological and geological limestone samples examined in this study: ICP-MS, ICP-AES and INAA. In this section, I discuss only how samples were prepared, analyzed and evaluated using these techniques. Strategies and factors that affected the choice of instrumentation used are discussed as the results are presented.

Limestone samples needed to be dissolved into solution for elemental analysis using ICP-MS and ICP-AES. Preparing the materials for both instruments was generally the same. For geologic samples this involved the removal of one gram of material from a freshly broken surface using a tungsten carbide drill. Depending on the size and condition of each archaeological sample, either the same procedure was used or a small chip (size > 1 g) of the material was powdered by hand in an agate mortar. For all samples exactly 0.004g of homogenized powder was weighed out and placed in a polyethylene analysis vial. One milliliter of nitric acid was added to each vial and the samples were left for 24 hours. Only the calcium carbonate components of the limestones were dissolved. Quartz, clay minerals and other non-carbonate constituents of the samples did not dissolve. After 24 hours the samples were filtered of any remaining mineral particulates and 19 ml of purified water was added. In approximately one half dozen cases an archaeological sample contained such a high level of quartz that little or none of it appeared to have dissolved at all. These samples were removed from the archaeological set (this accounts for the occasional skipped HLS sample number in the sequence listed in Appendix 11.1).

Prepared solutions were analyzed using one of the inductively-coupled plasma spectrometers in the LARCH. These instruments are capable of quantifying a wide range of elements at sub-parts-per-million levels. Each element that was measured was divided by measured calcium (Ca). This was done because the large component of quartz in these sandy limestones made it unclear precisely how much calcium carbonate was actually dissolved from sample to sample. Let me provide the following illustration: say for instance that two geologic samples came from the same source but less calcium carbonate

was dissolved in one of them due to the fact that it contained a higher amount of silica than the other. In the high silica sample 200,000 parts per million (ppm) Ca and 200 ppm barium (Ba) were measured. In the sample containing less silica 400,000 ppm Ca and 400 ppm Ba were measured. Both samples have ratios Ba/Ca of 0.001. Since equal amounts of material were weighed out for both samples the absolute concentrations of Ba per volume of calcium carbonate actually dissolved is the same in both cases. Dividing all measured elements by Ca in effect serves as an internal standard in the ICP.

The preparation, irradiation and count times for those limestones samples analyzed by instrumental neutron activation (INAA) were precisely the same as for other materials examined in this dissertation using this technique and so are not repeated here (see the INAA method section of Chapter 2).

After being log normalized, the data resulting from the ICP-MS/AES analyses and INAA were evaluated in a variety of manners. Bivariate plotting of two elements (divided by Ca and log normalized) in the dataset obtained by ICP-MS/AES was often sufficient to draw distinctions between geologic sources and determine the probable provenience of archaeological samples. Nevertheless, exploratory canonical discriminant analysis (CDA) was also performed to statistically evaluate the extent to which geologic formations could be distinguished from one another and the degree to which archaeological samples could be assigned to one of them. This method was used to examine data resulting from both ICP-MS/AES analysis and INAA. Issues relating to cross-validation of defined geologic sources (groups) and predicted group membership of archaeological samples were

previously discussed in Chapter 2. Appendix 11.6 lists the standardized (canonical) discriminant function coefficients for each of the figures that were generated using CDA.

Pilot study using the initial sample set

ICP-MS analysis of the initial set

The first analysis of the initial set was performed on the ICP-MS in the LARCH. Concentrations for the elements Al, Ba, Ca, Ce, La, Mg, Mn, Pb, Sr and U were obtained. However, only Ba, Ce, La and Sr were found to be useful for discriminating between the geologic sources. Except for these and Ca, which was needed to standardize the elemental concentrations, data for the other elements were discarded. The concentrations of the elements that were kept are reported in Appendix 11.2.

When the data were examined using simple bivariate plots of two elements (standardized and normalized) it was found that the best separation between geologic sources is achieved using Sr and Ba (Figure 11.12). When the six archaeological limestones from Harappa are superimposed (as black triangles) on that plot several things are suggested. First, it would appear that four of the samples resemble Pachchham limestone even though some of them fell around the margins of that group. HLS-4 in particular also plotted near the edge of the Jaisalmer group as defined by the Mool Sagar Khan (abbreviated MSK on the figures) samples. One sample (HLS-6) appeared more closely related to the limestones from the two deposits in the Jaisalmer region, both of which overlapped significantly. A final Harappan sample (HLS-3) plotted somewhat away from both groups (although closer to the Pachchham samples). This sample, importantly, is the micritic limestone that visually and texturally unlike the other archaeological fragments.

Figure 11.12: ICP-MS analysis of initial limestone sample set (bivariate plot).

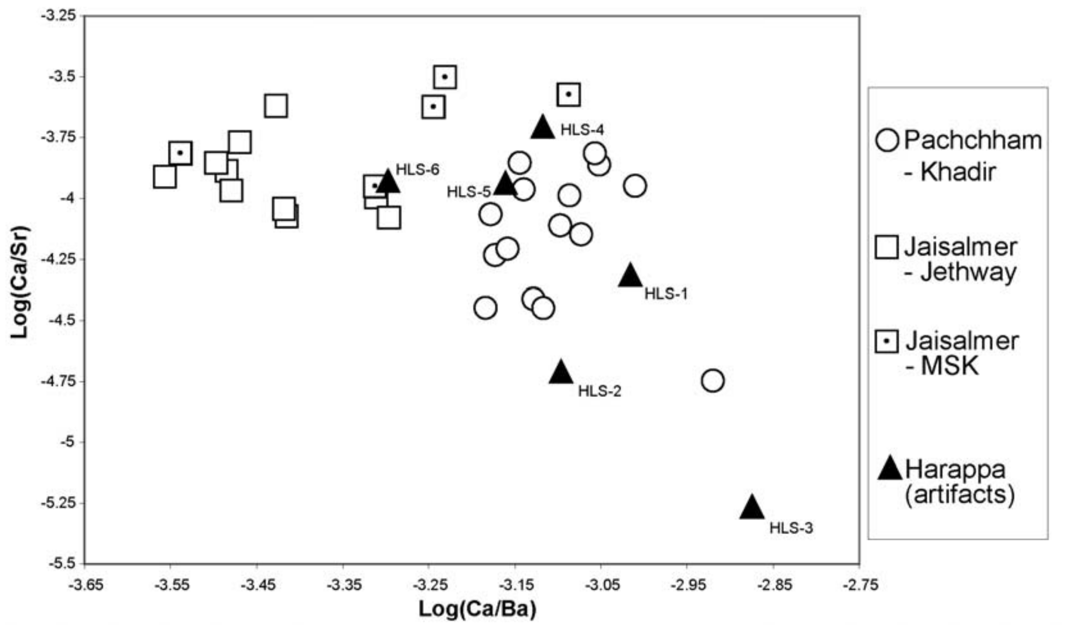
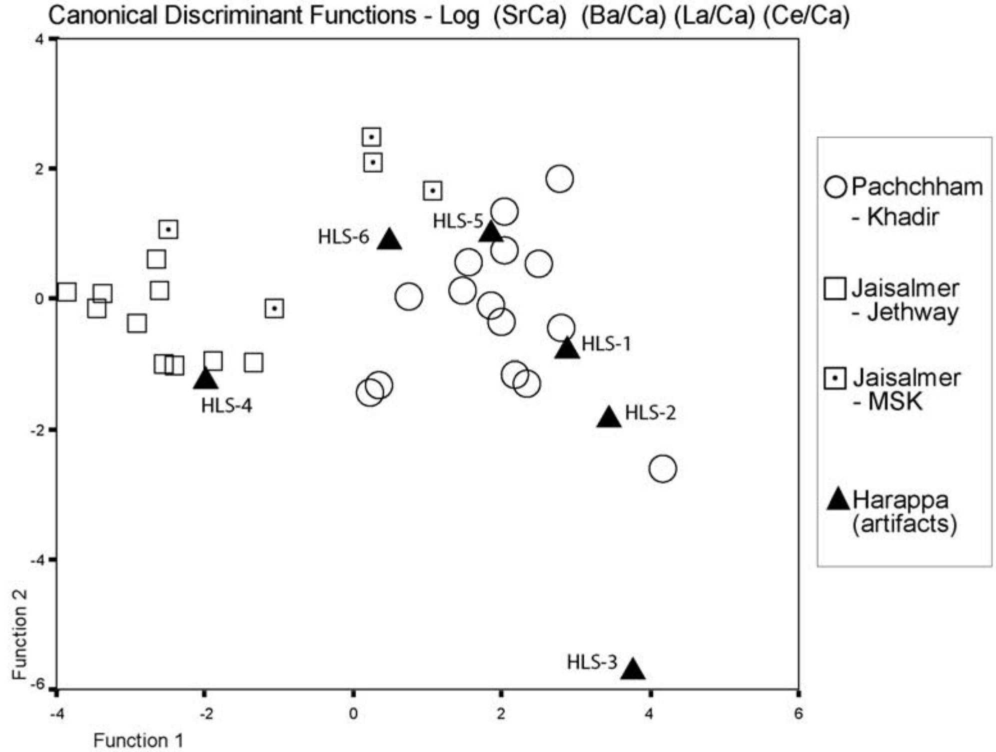


Figure 11.13: ICP-MS analysis of initial limestone sample set

Canonical Discriminant Functions - Log (SrCa) (Ba/Ca) (La/Ca) (Ce/Ca)



Next, the data were evaluated using CDA in order to get a statistically stronger sense of how different or alike the geologic sources and archaeological samples were (Figure 11.13). For this Ba, Ce, La and Sr values were used after being divided by Ca and log normalized. Good separation between sources was achieved with almost 87% of cross-validated cases in the three geologic groups classifying correctly. In this analysis, the predicted group membership for HLS-6 and HLS-4 (which straddled the margins of the two sources in the bivariate plot) was the Jaisalmer region. The remaining samples were assigned membership with the Pachchham group. However, we again see that HLS-3 is a distant outlier. Although it is closest to the center of the Pachchham group (and so was predicted to belong to it) it seems to be very unlike either that group or the other archaeological samples assigned to it.

The results of the ICP-MS analysis were very promising. Good separation between sources was achieved and the provenience determinations seemed to be fairly unambiguous, particularly when the data were evaluated using CDA. However, we (Dr. Burton and I) were cognizant of the fact that this method involved only a *partial dissolution* of samples. A large component of these sandy limestones was being discarded during the preparation process and with it data that might potentially yield very different results. It was decided that the results generated using partial dissolution and the ICP-MS could best be validated through a *whole rock analysis* of the initial dataset.

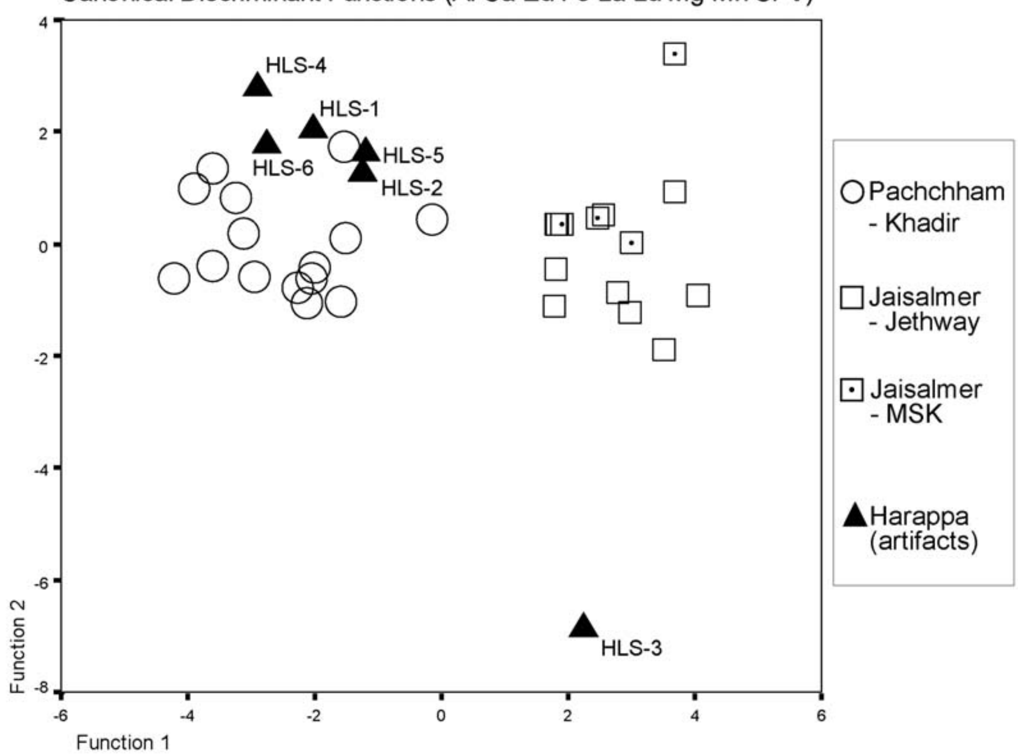
INAA of the initial set

A whole rock analysis was performed on the initial sample set using INAA. Of the data that were returned, ten elements (Al, Ca, Eu, Fe, La, Lu, Mg, Mn, Sr and V) that were

completely free of missing values were judged to be effective for use in discriminating between sources and assigning provenience to archaeological samples (Appendix 11.3). Due to a problem with the sample changing mechanism at the reactor lab, short count data for JLS-10 was not obtained. Therefore this sample had to be excluded. Elemental concentrations were log normalized before statistical analysis of the data.

Figure 11.14: INAA of the initial limestone data set.

Canonical Discriminant Functions (Al Ca Eu Fe La Lu Mg Mn Sr V)



Canonical discriminant analysis of the INAA data for the initial set (Figure 11.14) produced results that more or less approximated the data obtained through partial dissolution of samples and analysis using ICP-MS. Only around 65% of cross-validated geologic sample cases were correctly classified due to the large degree of overlap between the two sources in the Jaisalmer Formation. Excellent separation between the two limestone

formations was achieved however. Once again the single micritic sample from Harappa was clearly much different from the two sources or other archaeological samples. On the other hand, in this analysis, all of the remaining five samples were predicted to be members of the Pachchham Formation group. This is not entirely surprising as the two samples that had appeared more like Jaisalmer limestone in analyses of ICP-MS data had both plotted near the margins of the two groups of geologic samples.

Hierarchical cluster analysis (Appendix 11.7) indicates that a fair degree of overlap may, nonetheless, exist between the two geologic formations. Numerous clustering strategies were employed (the dendrogram in Appendix 11.7 was generated using median clustering and Pearson correlation) and each time there were invariably cases where archaeological samples that had been assigned to the Pachchham group using CDA appeared to cluster with members the Jaisalmer group. Likewise the clusters generated using the various strategies frequently contained examples from both geologic groups. This *may* indicate that demarcation seen between geologic groups when using CDA is not as sharp as it appears in a plot of discriminant functions.

Overall, however, the INAA results appear to confirm the patterns and provenience determinations suggested by the ICP-MS analysis. Based on this it was decided to significantly expand the archeological and geologic sample sets. Unfortunately at this time the ICP-MS at the LARCH was undergoing an extended period of maintenance. A decision was therefore made to analyze the initial sample set for a third time in order to see if the ICP-AES could be used as effectively as the ICP-MS for geologic provenience studies of limestone artifacts.

ICP-AES analysis of the initial set

Details of the detection capabilities of the ICP-AES used for this study were discussed in Chapter 2. Out of the various elemental data provided by this instrument, Ba, Fe, Mg and Sr (in addition to Ca of course) were deemed to be most useful for separating geologic sources and assigning provenience to archaeological samples. The absolute concentrations of the selected elements for these samples are listed in Appendix 11.4.

In a bivariate plot of Sr to Ba (standardized to Ca and log normalized) we see that although there is a degree of overlap between samples from the Pachchham and Jaisalmer formations, two reasonably distinct groups are evident (Figure 11.15). Samples HLS-4, 5 and 6 plot near margins of both groups and HLS-3 is again a distant outlier. A fairly similar pattern for the archeological samples is seen when the results of the ICP-MS analysis (Figure 11.12) were plotted in this way.

A degree of overlap again is evident between the two groups when the four measured elements are used in CDA of the sample set (Figure 11.16). In this instance 67% of cross-validated geologic cases classified correctly. The archaeological samples plotted as ungrouped cases repeat the previously seen pattern with HLS-3 yet again being the single distant outlier. Although the same three samples as before fall near the point of overlap between two geologic groups, the group membership predicted for all of the Harappan limestones (except the outlier) is the Pachchham formation.

In summary, reasonably good separation between the two limestone source formations was achieved using both bivariate plotting and CDA of elemental data obtained with the ICP-AES. Archaeological samples plotted in more or less the same manner using

Figure 11.15: ICP-AES of analysis of the initial limestone set (bivariate plot).

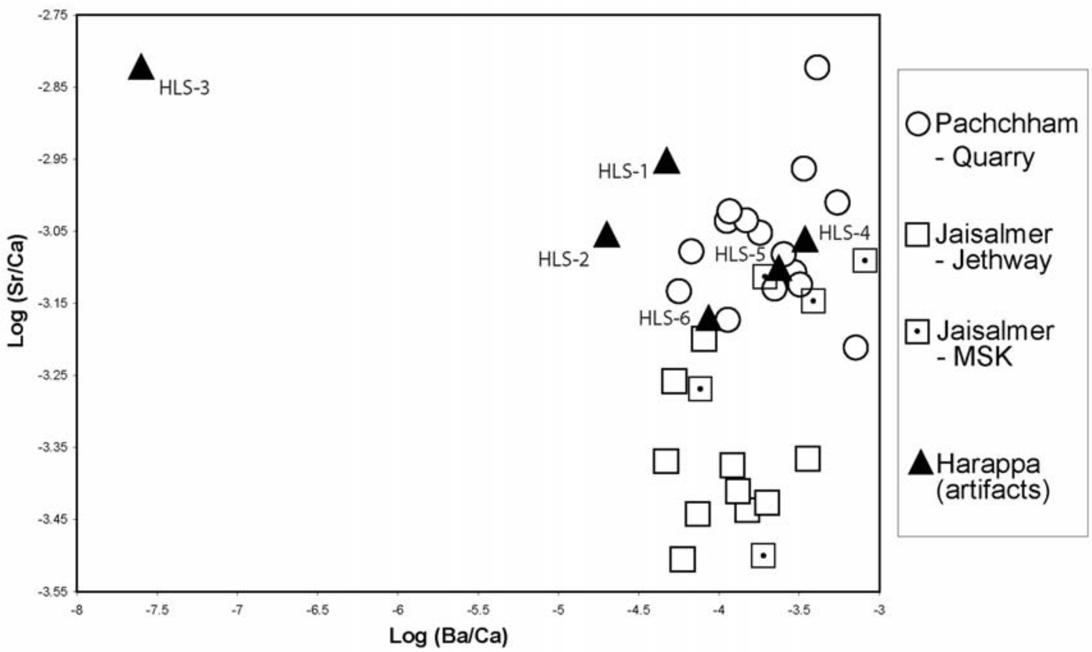
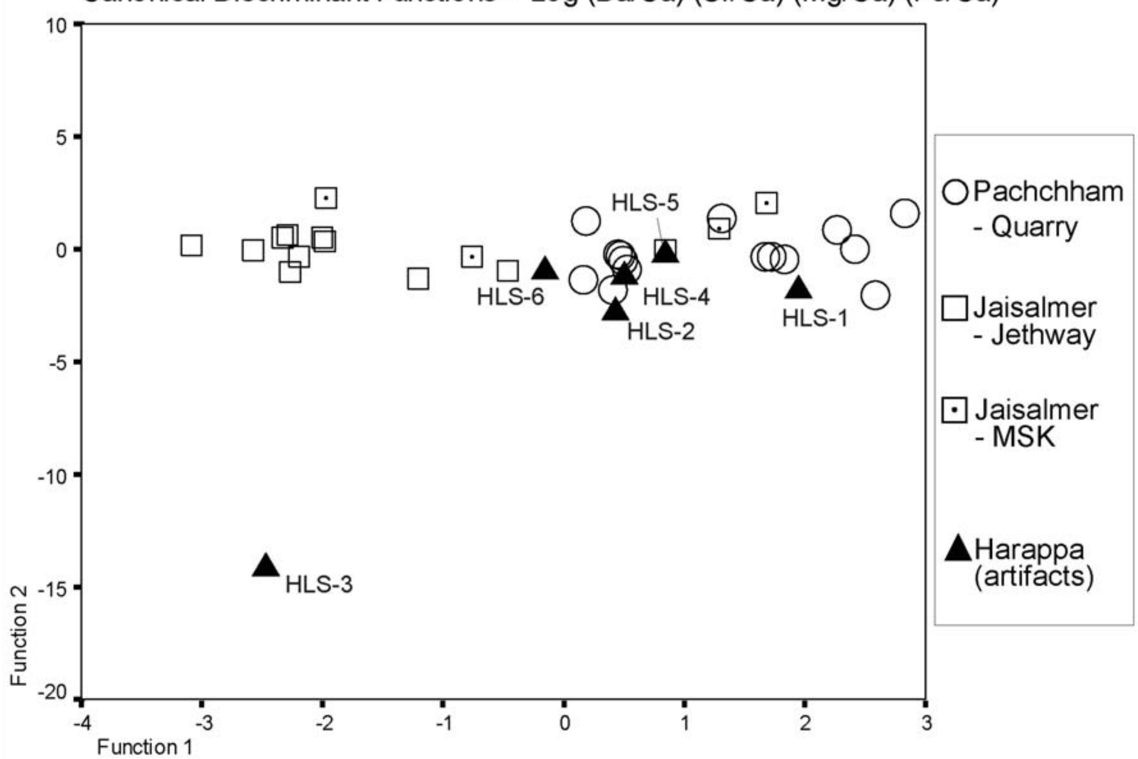


Figure 11.16: ICP-AES analysis of initial limestone sample set

Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)



either method of data evaluation. In addition and very importantly, the degree of geologic group separation as well as artifact plotting patterns and/or predicted group membership achieved with ICP-AES derived data were largely consistent with the results from the INAA and ICP-MS studies. Therefore, with a high degree of confidence that the ICP-AES could be used effectively for provenience analyses of limestone artifacts, the sample set was expanded to encompass 107 archaeological samples and 160 geologic samples.

Analysis of the expanded set using ICP-AES

Analysis using ICP-AES of the 267 samples comprising the expanded set took place over the course of two days. Data for the geologic samples is found in Appendix 11.4. Data for the limestone artifacts from Harappa, as well as listing of the probable geologic proveniences of those samples, can be found in Appendix 11.5.

Comparisons at the level of geologic formation

I begin the examination of the expanded dataset with comparisons of the Harappan limestone artifacts to source material at the broadest level – that of individual geologic formation. All samples from a single geologic formation are considered as a single group regardless of differences in macroscopic appearance or how far apart they were collected from one another. The Pachchham and Jaisalmer formations are compared with the new group of 25 micritic limestone samples from the Rohri Hills. These samples were collected at the same four locations as the Rohri chert samples analyzed in Chapter 6. It was decided to add this group of Rohri Hills limestone to the set for two reasons: First, over a dozen of the samples in the archaeological set were micritic limestones. Even though there were no

samples from other micritic limestone sources available for comparison it would still be informative to know how closely the Harappan samples are to the Rohri limestones. Many Harappan sites, including the city of Mohenjo-daro, are located in the general vicinity of the Rohri Hills. Secondly, in order to create a broad-scale display of data points on an *x-y* axis using CDA a third group was needed in order to generate a second discriminant score.

Samples from the three geologic sources alone are displayed in Figure 11.17 using a bivariate plot of their Ba and Sr values (divided by Ca and log normalized). Although there is a fair degree of sample overlap in some areas along the margins the geologic groups, the three sources appear to be reasonably distinct.

In Figure 11.18 the archaeological samples from Harappa are superimposed as black triangles. With over 250 points now plotted the figure becomes very *busy* visually. Lines and shading have therefore been added to show the extent of the areas where geologic sources plot. Such additions, which are used frequently in upcoming figures, are only meant to be visual aids and do *not* represent confidence intervals of any kind. In this view, it is evident that the majority of archaeological samples (most of which are types of sandy limestone) fall within the area encompassed by the Pachchham Formation. A significant number of the remaining samples plot either with the Rohri Hills group or outside of all three groups. Two artifacts (HLS-10 and HLS-48) plot squarely within the Jaisalmer group. Many samples fall in and around the area where the Pachchham and Jaisalmer groups overlap. This area is where three of the original six artifacts from the initial set consistently plotted. Those six are identified on the figure in order to provide a

Figure 11.17: ICP-AES analysis of expanded geologic sample set (bivariate plot)

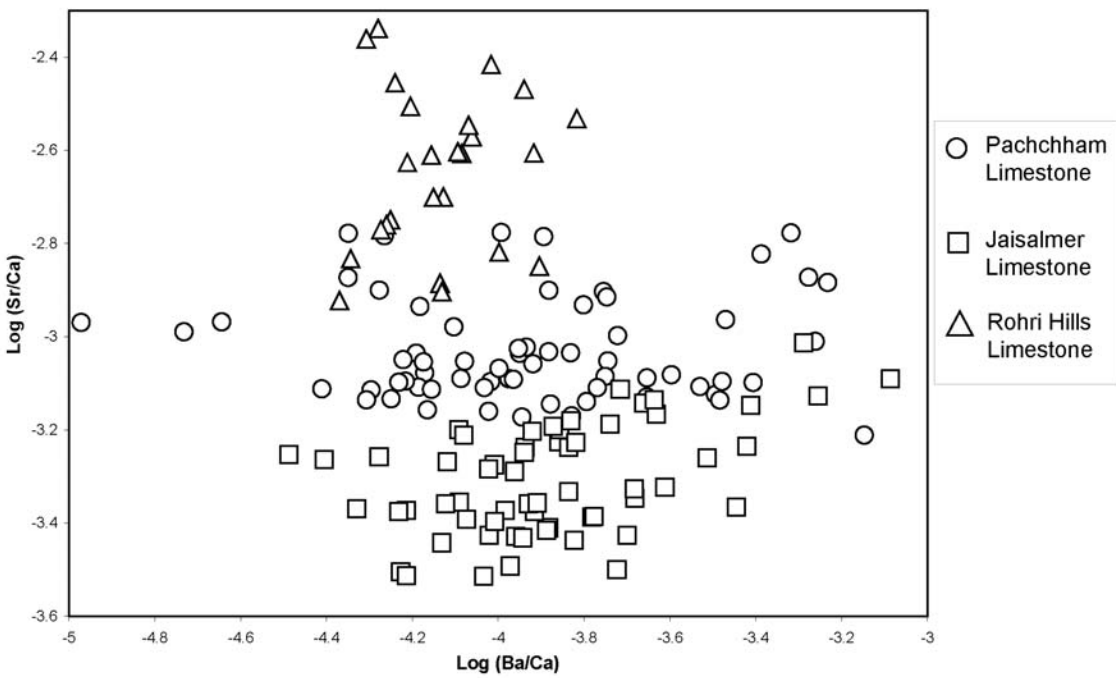
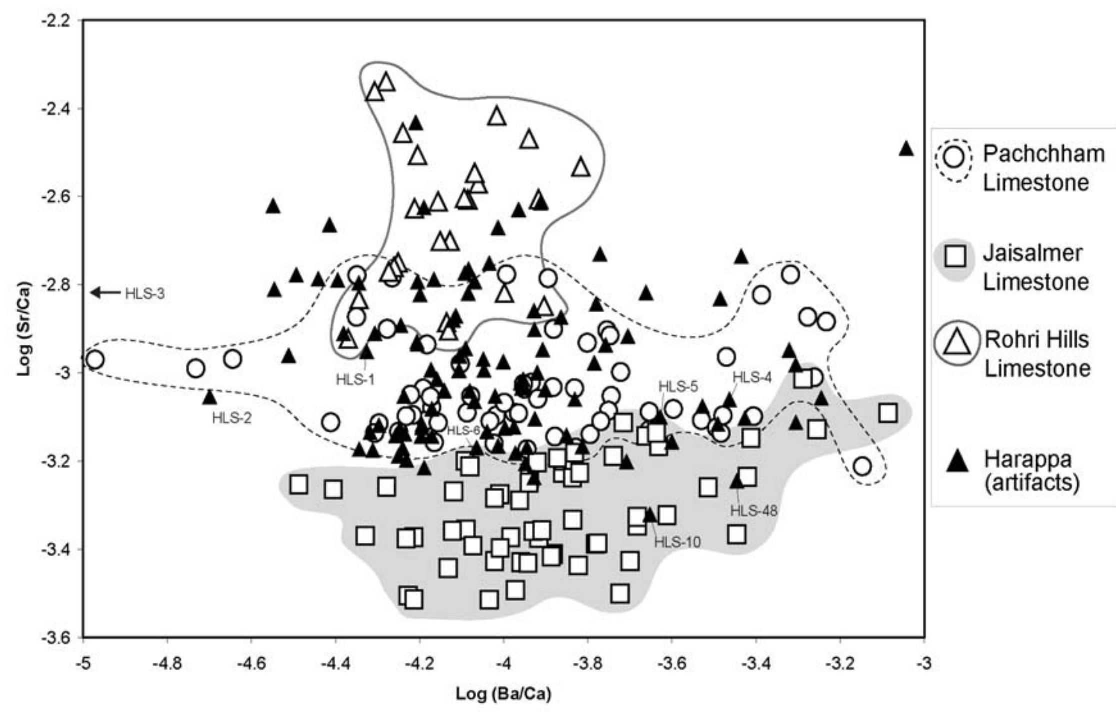


Figure 11.18: ICP-AES analysis of expanded archaeological sample set (bivariate plot)



sense of how the expanded number of geologic samples might, or in this case might not have, helped to clarify the boundaries between the formations.

Far better separation between geologic sources is achieved when the dataset is examined using CDA (Figure 11.19). The samples from the Rohri Hills, so different in geologic age and appearance than the sandy limestone sources, form very a distinct and separate group. Although a degree of overlap is still present between the Pachchham and Jaisalmer groups, 93.3% of cross-validated geologic cases classified correctly.

When the archaeological samples are considered as ungrouped cases (Figure 11.20), the large majority once again cluster with the Pachchham group. Many samples also fall either in the Rohri Hills group or outside of all three groups. The two artifacts that had plotted in the Jaisalmer group in the bivariate plot now fall away from that group. However, the predicted group membership (based on distance to the Jaisalmer group center point as compared to the other group's center points) of those and four other samples is the Jaisalmer group.

The purpose of this first look at the expanded set was not to assign provenience to archaeological samples. The primary purpose was to determine which method of looking at the data (bivariate plotting or CDA) produced the best results. Best separation between groups was achieved using CDA and, therefore, this method is the one used for all remaining evaluations of the dataset. Another purpose was to get a general sense of how the archaeological samples grouped when compared with the expanded geologic dataset. The majority of artifacts seem to group with the Pachchham Formation. However, many of

Figure 11.19: ICP-AES analysis of expanded geologic sample set

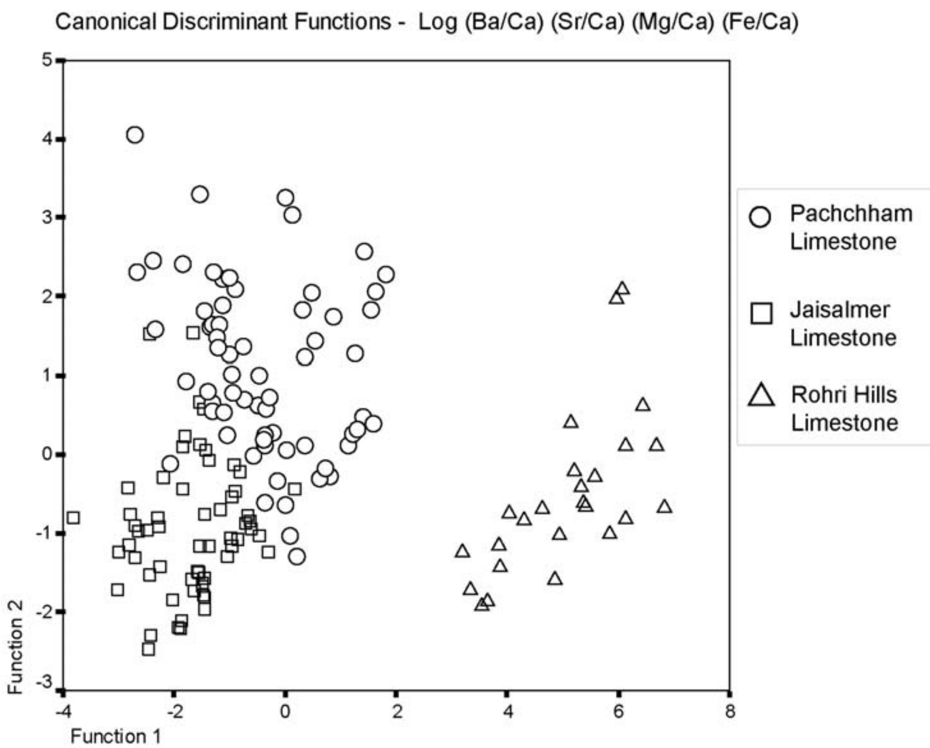
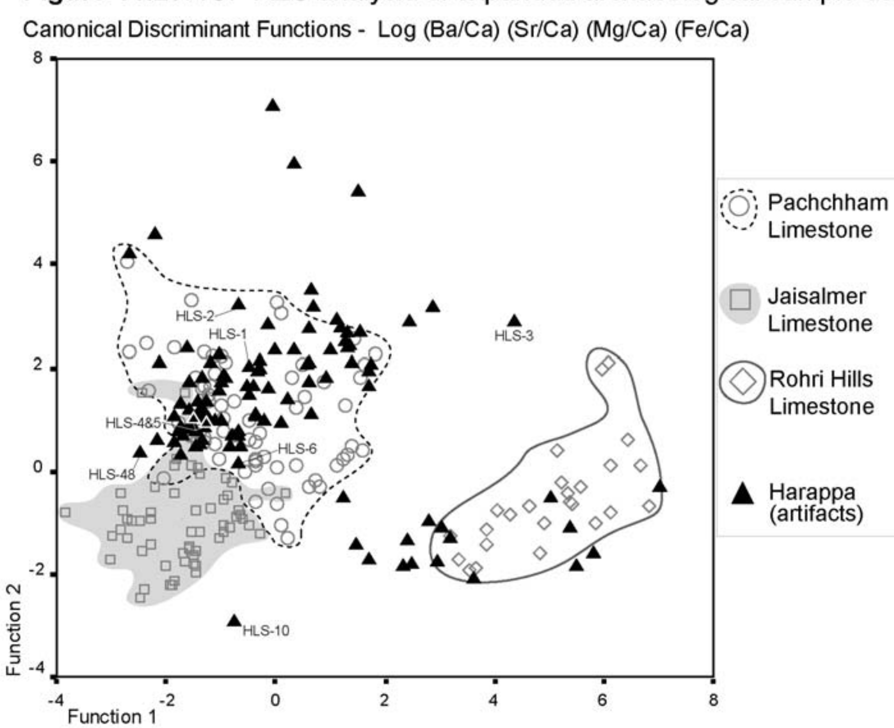


Figure 11.20: ICP-AES analysis of expanded archaeological sample set



those fell in the area where that group overlapped with the Jaisalmer Formation. A significant number of others were probably unrelated to either those two groups. In order to determine the probable geologic provenience of the archaeological samples, I now begin to examine the dataset by focusing on the individual material types defined earlier in this chapter

Banded yellow-brown and yellow-brown sandy limestone

Let us first examine banded yellow-brown and yellow-brown sandy limestone artifacts. The 31 examples from Harappa in this visual type category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.21). The black triangles with white circles on the figure identify samples taken directly from the two banded yellow-brown ringstones from the Harappa Museum's reserve collection (HLS-7 and HLS-8, pictured in Figure 11.4 D). At this level (in which 93% of cross-validated geologic samples classified correctly) the predicted group membership of all samples is the Pachchham Formation. Many of the artifacts do, however, cluster near the area where outliers of the Jaisalmer group overlap with the Pachchham samples.

In the next view (Figure 11.22) we examine the Pachchham and Jaisalmer formations at the level of the individual locations from where geologic samples were collected. The Rohri Hills samples have been discarded while two yellow sandy limestone fragments from the Kirthar Range of Sindh were added. The cross-validation score at this level dropped significantly (to around 62%) due to the high intra-formation overlap between sampled locations. Nonetheless, 28 of the 31 artifacts had a predicted group

Figure 11.21:ICP-AES analysis of banded yellow-brown limestone artifacts

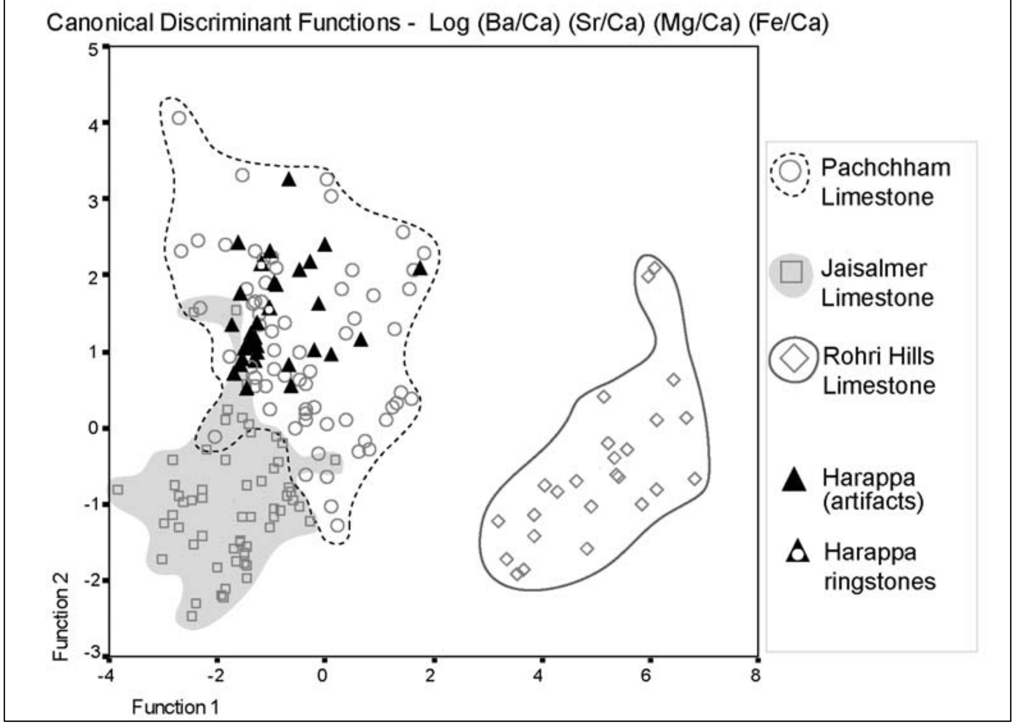
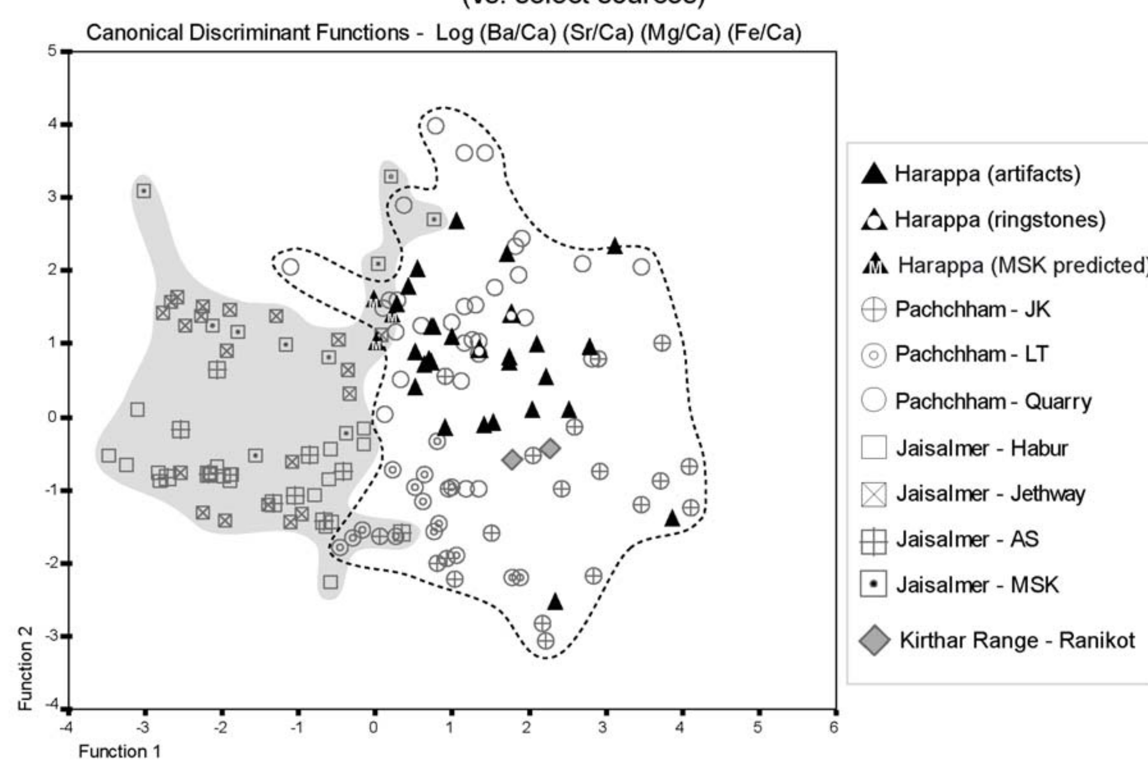


Figure 11.22: ICP-AES analysis of banded yellow-brown limestone artifacts (vs. select sources)



membership in the Pachchham formation. Twenty of those 28 artifacts, including the two banded ringstones, were assigned to the Khadir Island Harappan quarry group (Quarry) and the remaining eight to the Pachchham Island Juni Kuran (JK) group. Three samples, however, were predicted to belong to the Mool Sagar Khan (MSK) group of the Jaisalmer Formation. These sample points are marked with the letter "M." Note that three other artifacts group adjacent to those samples. Although predicted to belong to the Pachchham group, those may actually belong with those artifacts assigned to Mool Sagar Khan. On the other hand, all of the artifacts in this area (even the MSK ones) may simply be outliers of the Pachchham Khadir Island quarry group. When the Mool Sagar Khan, Khadir quarry and Juni Kuran sources were compared alone (not shown) only a single sample was predicted to belong the Mool Sagar Khan group.

Although the two yellow sandy limestone samples from the Kirthar Range in Sindh did plot among the Pachchham geologic group, none of the artifacts examined appeared to resemble them. However, it would be imprudent to state that Harappan yellow limestone could not have come from the Kirthar Range, especially after having only analyzed a mere two samples from that region. What is very clear is that the majority of the 31 banded yellow-brown and yellow-brown sandy limestone artifacts examined here more closely resemble Pachchham limestone than they do Jaisalmer limestone or the Kirthar samples.

Bright yellow-red sandy limestone (Jaisalmer stone?)

Now we turn to the category of sandy limestone artifacts that bears a very strong resemblance to Jaisalmer stone. Twenty-two artifacts made up this sub-set of bright yellow to bright yellow-red sandy limestones.

The 25 examples in the dataset of this macroscopic category are plotted as ungrouped cases against samples from the Pachchham, Jaisalmer and Rohri Hills limestone formations (Figure 11.23). It immediately is evident that this group and those in the previously examined banded yellow-brown sandy limestone category (Figure 11.21) plot in a very similar way. At this level, 19 of the Harappan artifacts are classified as belonging to the Pachchham Formation. Three are assigned to the Jaisalmer group.

When individual sources in the Pachchham and Jaisalmer groups are compared alone (Figure 11.24), 18 of the Harappan samples are assigned a predicted group membership with Pachchham sources on Khadir Island, Kutch (17 to the Harappan quarry and one to the nearby Limdiwali Tari area) and four are predicted to belong to the Mool Sagar Khan source in the Jaisalmer Formation (noted on the figure with an “M”). When the archaeological samples are compared to those four assigned sources alone (not shown), Mool Sagar Khan looses one member while Limdiwali Tari gains one.

These results would seem to suggest that the many of the artifacts identified as Jaisalmer stone by past excavators of Harappa (and Mohenjo-daro) may in fact have come from sources in Kutch. However, three to four of the Harappan artifacts were predicted to belong to Mool Sagar Khan in the Jaisalmer Formation and I believe that at least some of the other artifacts in this sub-set may have been incorrectly classified as coming from Pachchham sources. For example, sample HLS-044 (noted on Figure 11.24 and pictured in Figure 11.9 D) is an artifact from Harappa that has the same bright yellow-red of classic Jaisalmer stone (Figure 11.10 A & B) but is predicted by CDA to belong to a Pachchham source. None of the stone that I have seen to date from sources in Kutch, however, have

Figure 11.23: ICP-AES analysis of yellow-red sandy limestone artifacts.

Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)

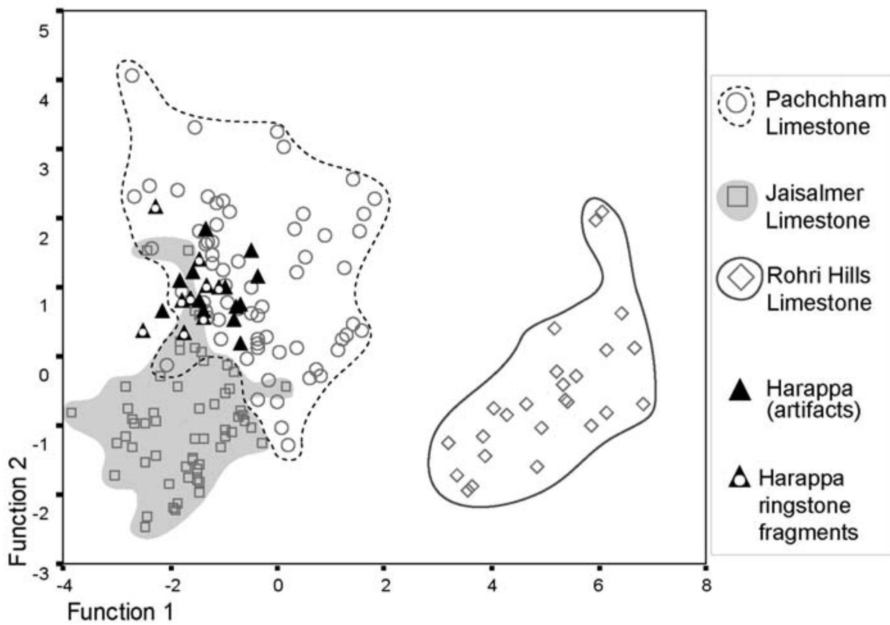
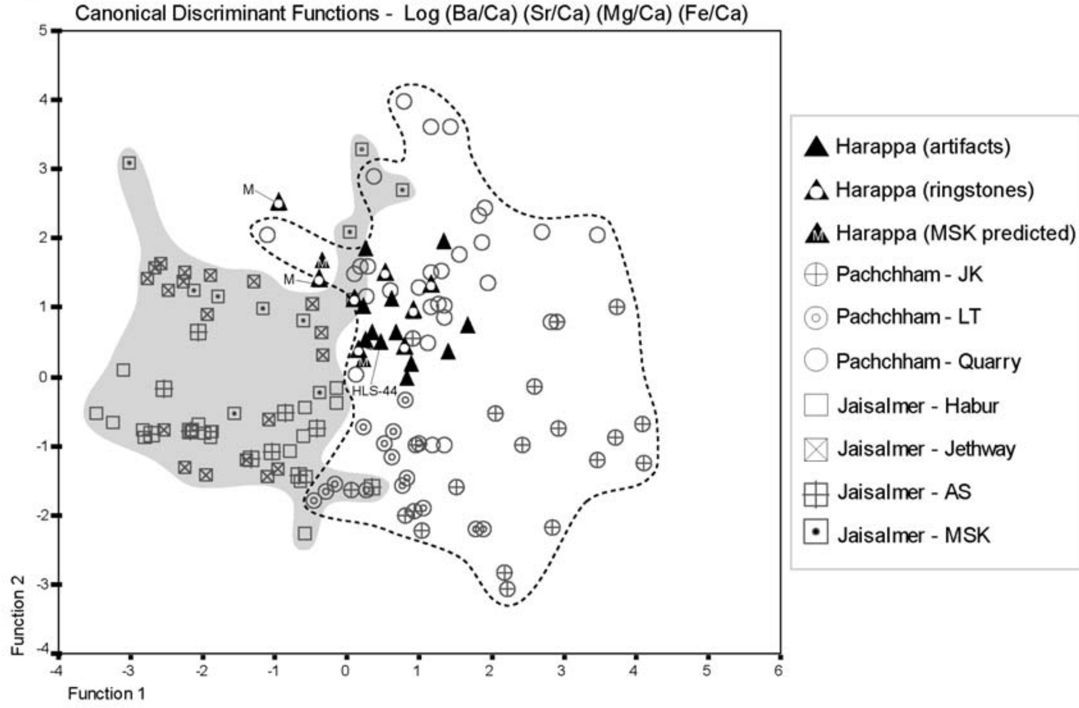


Figure 11.24: ICP-AES analysis of yellow-red sandy limestone artifacts (vs. select sources)

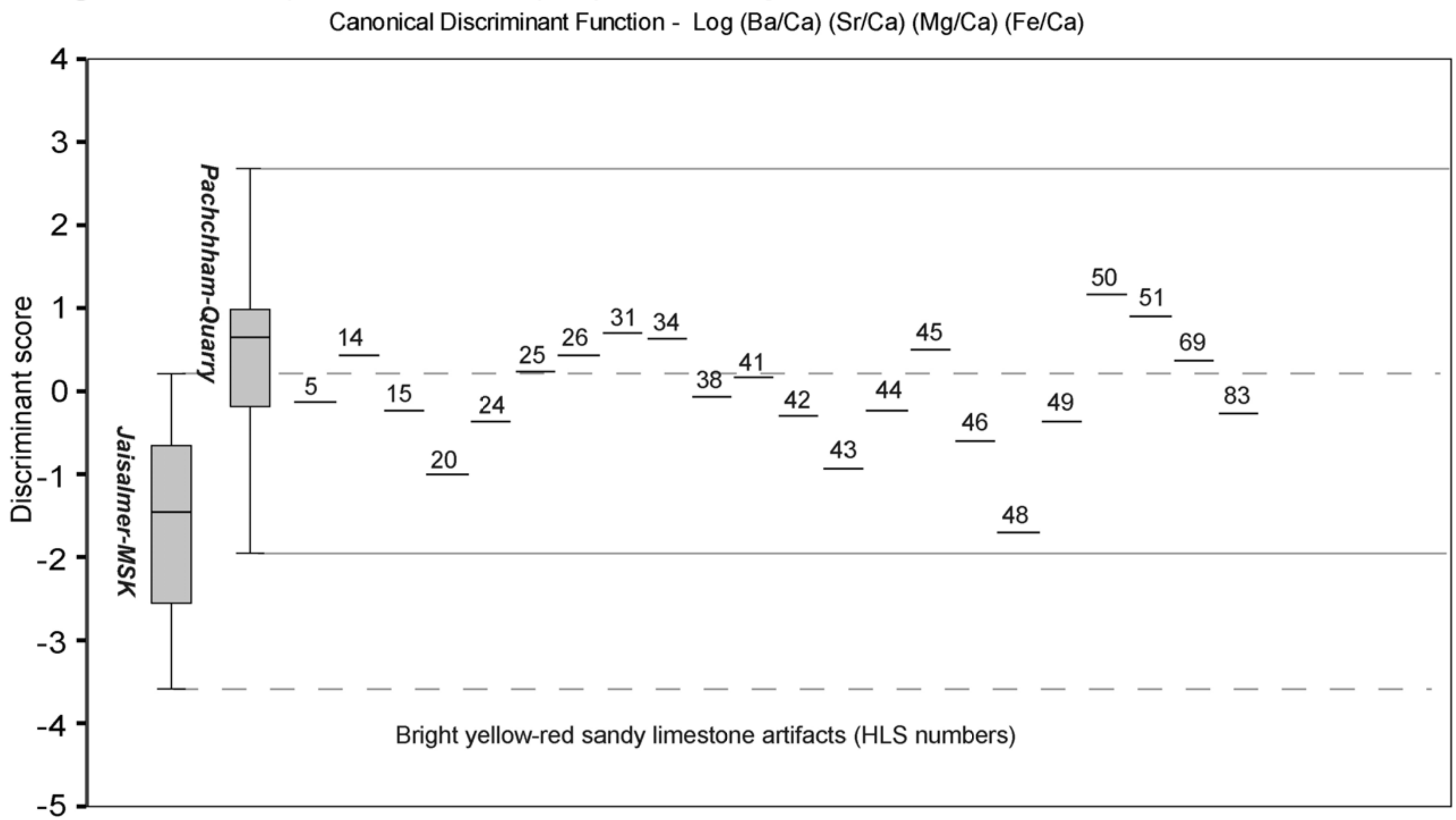
Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)



quite the same "golden" yellow hue of this or many other samples in this category – but granted, I have only visited a handful of located within that region.

Perhaps the possibility that some artifacts *may* have been misclassified using CDA can be best illustrated by comparing the two overlapping sources alone. Figure 11.25 is a box plot (recall how this was previously used in Chapter 8 to compare agate artifacts to geologic samples from two sources – Figure 8.16) based on the discriminant scores generated when the Mool Sagar Khan (Jaisalmer) and the Khadir Island quarry (Pachchham) were compared alone and the bright yellow-red limestone artifacts were considered ungrouped. I have added horizontal lines indicating where the furthermost outliers of both geologic sources are. Dashed gray lines indicate Mool Sagar Khan and solid ones indicate the Khadir quarry. Artifacts are plotted individually and labeled. The box plots clearly show that a significant amount of overlap exists between the two sources (80% of cross-validated cases were correctly classified) and that all of the archaeological samples plot within the area encompassed by the Pachchham limestone quarry on Khadir. However, 15 of the 25 also plot below the Mool Sagar Khan outlier with the highest discriminant score (marked with the top-most dashed line) and so could *potentially* belong to that group. HLS-044 is among those that plot in this way. Based on this fact and the artifact's appearance I am inclined to re-classify it as Jaisalmer stone. In the fifth column of Appendix 11.5 the probable proveniences of archaeological samples are listed. I have marked the original source assessment of that sample (Pachchham Formation – Khadir quarry) and other artifacts similar to it with the notation "*possibly MSK."

Figure 11.25: Box plot of Pachchham quarry vs. Mool Sagar Khan and artifacts based on discriminant scores



Gray-red sandy limestone

The final macroscopic category of sandy limestones to be considered is the gray to gray-red type. Among the 33 artifacts in this sub-set are fragments of three large gray ringstones (one of these, HLS-66, is pictured in Figure 11.9 F), many architectural elements and the shoulder/haunch piece of the large bull sculpture/frieze from Mound AB.

When the 33 gray-red sandy limestone artifacts are plotted against the Pachchham, Jaisalmer and Rohri Hills formations (Figure 11.26) we see that, like the previous two sub-sets, the majority cluster within Pachchham group. Unlike the previous sub-sets, however, most of these plot well away from the area where the Pachchham and Jaisalmer groups overlap. At this level of analysis the predicted group membership for 32 of artifacts is the Pachchham Formation. Only HLS-98 was assigned to the Jaisalmer group.

Next the individual sources comprising the Pachchham and Jaisalmer groups are compared alone and the archaeological samples are plotted as ungrouped cases (Figure 11.27). It is even more evident now that artifacts of this macroscopic type plot differently overall than the banded yellow-brown and bright yellow-red types. Twenty-five of the 33 samples are predicted to belong to the Juni Kuran group, which is where the gray type of Pachchham limestone is best developed. The three large fragments from the gray wavy ringstones plot squarely in the center of that group. Seven artifacts are closer to the centroid of Khadir quarry group and therefore assigned to it. Some of those, however, samples may be outliers belonging to the Juni Kuran group. More distant outliers (noted on the figure with their HLS numbers) may be from a different sources altogether. One of these outliers is the sample taken from bull sculpture. It appears quite distinct from most of

Figure 11.26: ICP-AES analysis of gray and red sandy limestone artifacts.

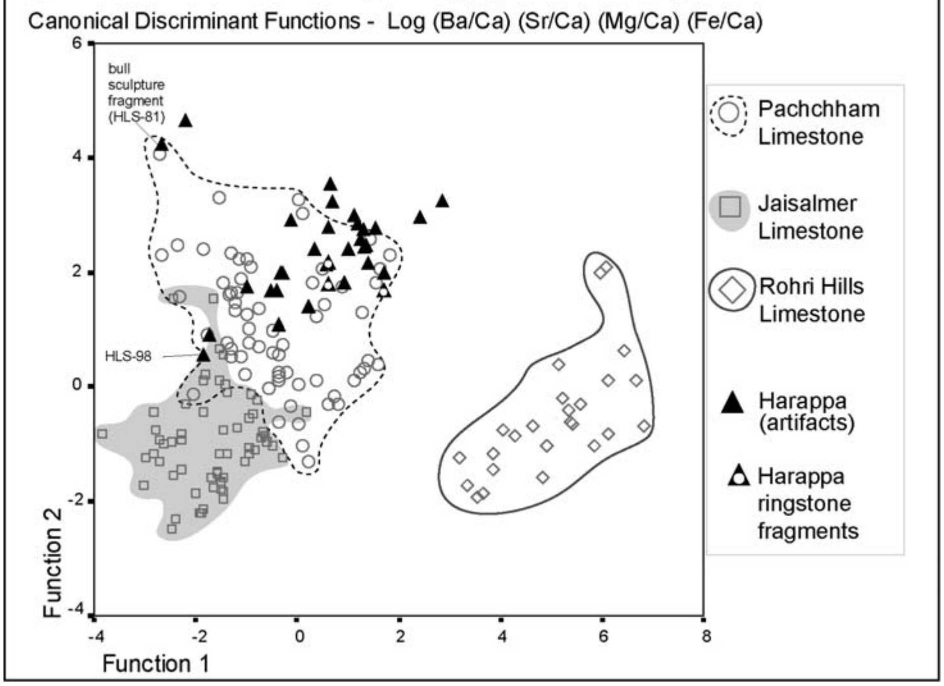
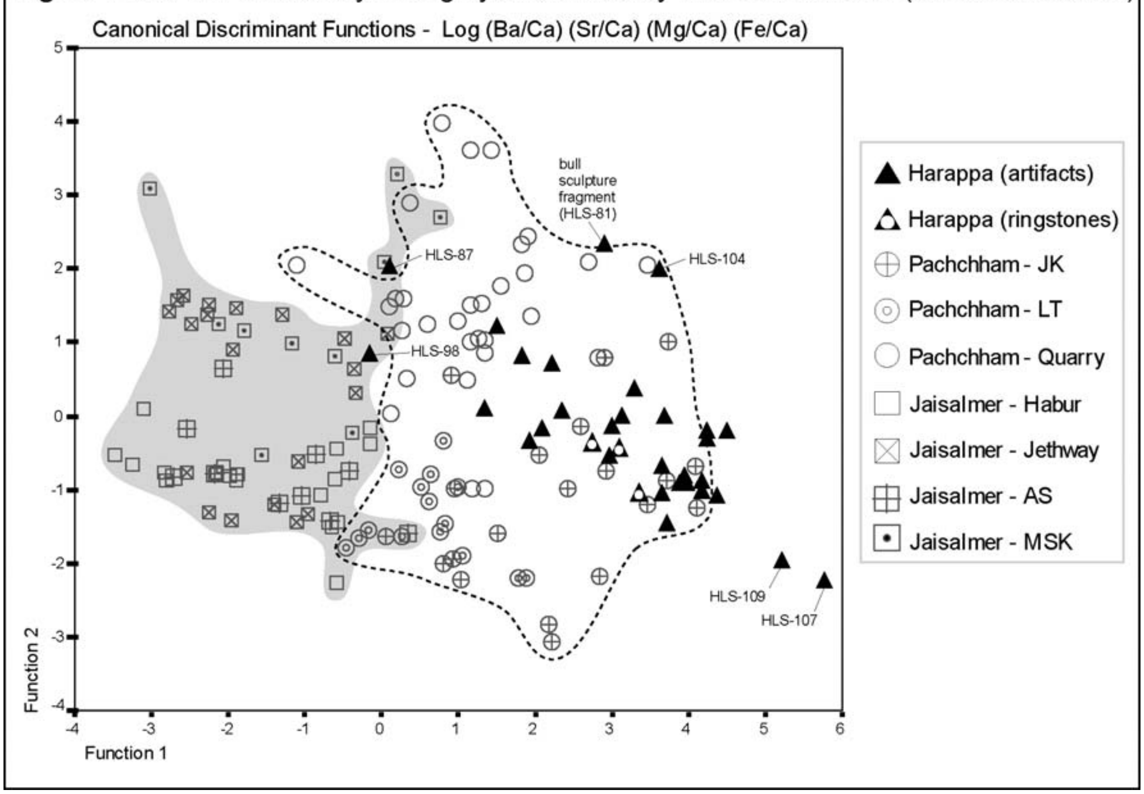


Figure 11.27: ICP-AES analysis of gray and red sandy limestone artifacts (vs. select sources)



the other samples in thee sub-set. HLS-98 is once again assigned to the Jaisalmer Formation at Mool Saga Khan. This particular artifact is more reddish brown than gray and could conceivably have been carved from a large red patch in a piece of Jaisalmer stone.

Micritic limestone

Micritic limestones are found in numerous locations around the Greater Indus region. For this study, only 25 samples from one source formation, the Rohri Hills of central Sindh, were available with which to compare to the 13 micritic limestone artifacts in the sample set. The majority (n=16) of the micritic limestone samples from the Rohri Hills come from the outcrop directly adjacent to the Early Harappan and Harappan Period site of Kot Diji (Khan 1965). The remaining nine samples are from various outcrops extending from Rohri town in the north to Kandarki in the south (these locations are discussed in greater detail in the Rohri Chert section of Chapter 6). Although having samples from micritic sources in other regions would be preferable, useful information can nonetheless be gained by determining how similar or dissimilar the Harappan micritic limestone artifacts are to samples from the Rohri Hills.

We see that the 13 micritic limestone artifacts from Harappa spread widely when plotted as ungrouped cases against the Pachchham, Jaisalmer and Rohri Hills formations (Figure 11.28). A handful of artifacts fall in or near the Rohri Hills group but the rest, including the large block that may have been a drain cover (Figure 11.6 B) and the single micritic sample in the initial archaeological set (HLS-3), seem to be unlike limestone from that formation. This would suggest that multiple sources of micritic limestone were used by residents of Harappa.

Figure 11.28: ICP-AES analysis of microcrystalline limestone artifacts.

Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)

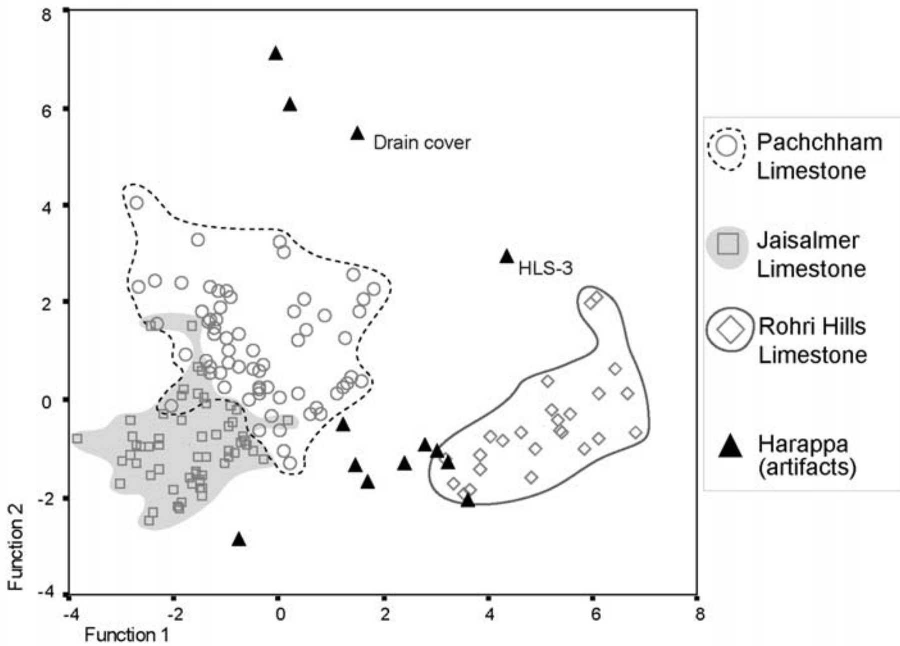
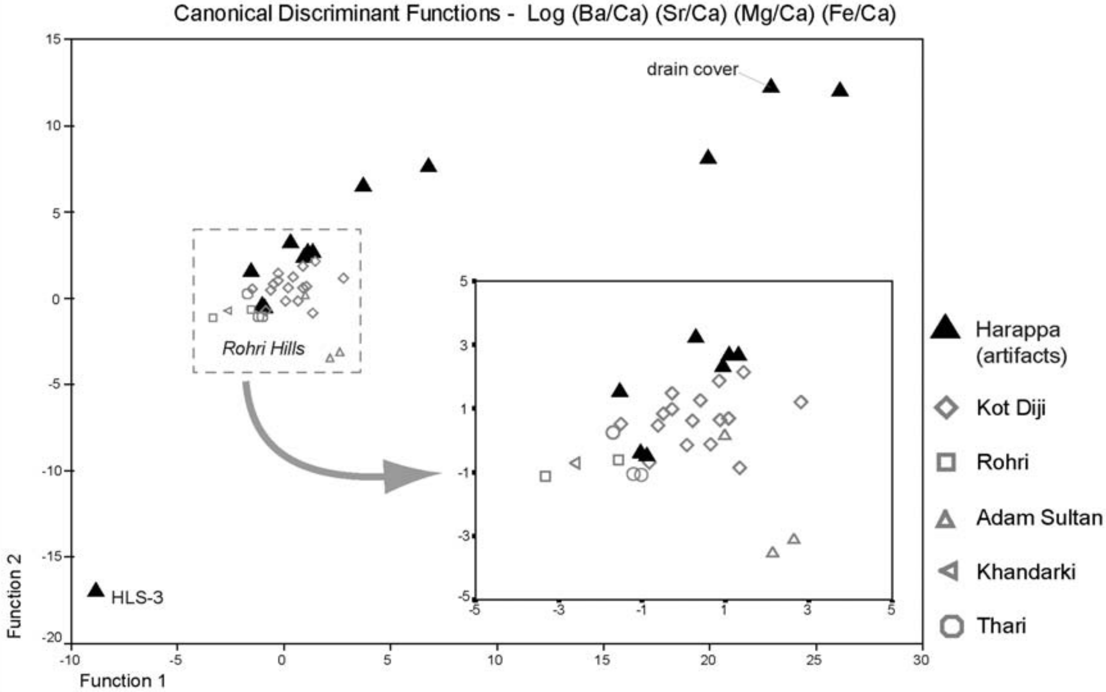


Figure 11.29: ICP-AES analysis of microcrystalline limestone artifacts (vs. Rohri Hills sources)

Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)



How similar or dissimilar the Harappan artifacts are to Rohri Hills limestone becomes even more evident when the other formations are discarded and the various sources within the Rohri Hills group are considered alone (Figure 11.29). Again the drain cover (HLS-3) and several other samples plot away from the Rohri Hills group. Seven artifacts, however, do closely cluster with the geologic samples. Until samples from other micritic sources can be analyzed I provisionally suggest that Harappans acquired this type of limestone from multiple sources and one of them was likely the Rohri Hills.

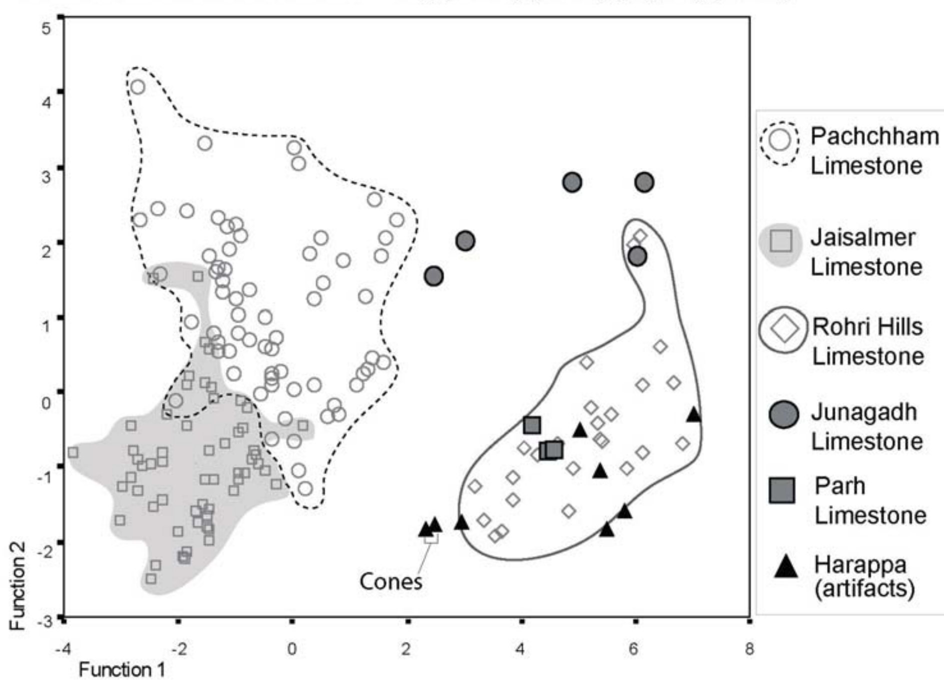
White chalky porcelaneous limestone

White chalky porcelaneous limestone is the final type of material in the archaeological set and are now briefly examined. This sub-set of consists of samples taken from six non-descript fragments and two from a pair of large conical objects. The cones are pictured in Figure 11.5 A and are likely same the two reported by Vats (1940: 51) as coming from Trenches III and IV. Although none of the limestones from the three main geologic sources examined in this study much resembles the artifacts, a eight samples from two sources of white limestone have been added to supplement the geologic set. Three of the additional geologic samples are white porcelaneous Parh limestone (pictured in Figure 11.5 B) collected near the site of Dabar Kot (Fairservis 1959) in the Loralai District, northern Balochistan. Five others are a soft chalky white limestone from Adityana in the Junagadh Distinct of Saurashtra (Desai and Pathole 1979). Although the latter tends to be a much softer material than the white limestone from Harappa, I have included it in this analysis in order to provide another group for comparison.

When plotted against the geologic samples we see that the eight white limestone artifacts cluster in or near the Rohri Hills group (Figure 11.30). Although I have not seen or heard of any chalky white limestone in the Rohri Hills, this is not to say it could not occur at some point along its approximately 80 km length. Interestingly, the three Parh limestone samples plot within the Rohri Hills group and a couple of the Harappan artifacts fall near them. Parh limestone is "exposed extensively in the Kirthar-Sulaiman region" (Kazmi and Jan 1997: 95). It is possible then that the white limestone artifacts may derive from one of these regions west and southwest of Harappa. The samples from the two cones plot very close to one another confirming that were probably made from the same stone, probably at the same time. They are quite distinct from both the chalky white limestone from Adityana, Gujarat and the Parh limestone samples from Loralai, Balochistan.

Figure 11.30: ICP-AES analysis of white limestone cones and fragments

Canonical Discriminant Functions - Log (Ba/Ca) (Sr/Ca) (Mg/Ca) (Fe/Ca)



Section summary

Good separation overall between the geologic sources of sandy limestone (Pachchham and Jaisalmer) was achieved using CDA on ICP-AES derived data, although there was a degree of overlap between the two. When compared as ungrouped cases, many of the archaeological samples fell in and around the area of overlap. Most of the three types of sandy limestone artifacts from Harappa were predicted to belong to sources within the Pachchham formation of Kutch. Some samples of each of the types, however, did fall close enough to geologic groups in the Jaisalmer formation of western Rajasthan to be assigned that provenience. Those that did so may simply be outliers of Pachchham limestone. Or they may actually come from Jaisalmer sources, along with many other artifacts that plotted in or near the area of overlap and were assigned to Pachchham sources. Those bright yellow-red sandy limestones artifacts that that fell within the range of variation for the Mool Sagar Khan source and *look* like Jaisalmer stone, very probably are Jaisalmer stone. So in the end the provenience determination made by past and present excavators based on the appearance of those artifacts was likely correct in most cases.

Most of the banded yellow-brown sandy limestone artifacts analyzed were clearly analogous to Pachchham limestone. The majority (especially the two large ringstones) grouped closely with samples taken from the Harappan period quarry near Dholavira. Similarly the gray-red sandy limestone artifacts largely corresponded with the Pachchham limestone deposits of Pachchham Island – an area that is notable for the gray type that occur there. It is always possible that sources of limestone resembling these types will be identified elsewhere or that fuller characterization of the Jaisalmer Formation may

eventually result in the need to reclassify the provenience of those artifacts. The same may be the case when a larger set of samples from the Kirthar Range are eventually analyzed. However, at this time, the results strongly suggest that most examples of these sandy limestones used for large objects at Harappa derived from sources 800 km away in Kutch.

The analysis of micritic limestones in the sample set indicated that materials from multiple sources (three or more) were brought to Harappa. This is not particularly surprising as micritic limestone formations practically line the Indus Basin (particularly on its northern and western margins). A group of the Harappan artifacts appeared to be very similar to geologic samples analyzed from Rohri Hills of Sindh indicating that source *may* have been one of the ones used. However, as no other geologic sources of micritic limestone were available for comparison that conclusion should be considered tentative.

The series of chalky white porcelaneous limestone artifacts analyzed were most geochemically analogous to samples from the Rohri Hills of Sindh, although no occurrences of that type of limestone has been reported from that formation. Three samples of white Parh limestone from Balochistan were analyzed and did appear somewhat like several of the Harappan samples. Although white limestone artifacts at Harappa most probably did come from Balochistan, much more work remains to be done before they can be assigned to any particular formation.

Discussion – Large limestone objects at Harappa in context

Indus craftspeople used limestone to create many different kinds of objects. Some of the limestone artifacts excavated at Harappa are small in size – cubical weights, beads, inlays, discs, balls and mace heads. The great majority, however, are either bulk stone

objects (as defined in Chapter 1), broken pieces that were clearly a part of such objects at one time or non-descript flakes and chunks. The flakes and chunks themselves tend to be comparatively big in size (e.g. bigger than is typical of other kinds of stone debris) and may represent waste produced during the manufacture of bulk-sized limestone objects. Or they might simply be non-diagnostic pieces broken off of already finished items of that kind. Whichever the case may be, after grindingstones (Chapter 5), most of the artifacts in Harappa's rock and mineral assemblage that fall into the bulk size/weight category are composed of one of the types of limestone discussed and analyzed in this chapter. As I have shown, several of these types seem to have been obtained from sources as far away as Kutch. In this final section, I discuss the spatial and temporal contexts that large limestone artifacts appear in at Harappa, as well as the possibility that their use may have represented a new form of social expression for certain groups of Indus Civilization peoples.

The 107 seven limestone samples analyzed for this study represent a little over one-third of the total assemblage for this material variety. The excavation trenches that those samples came from are marked in red on Figure 11.31. During the period of time that limestone was used most intensively at Harappa (Period 3C – discussed below) it is found on every mound at the site. The photographs on the figure are intended to selectively illustrate how the five main types of limestone do not appear to have been restricted to one area or another. For examples, the relatively abundant type yellow banded sandy limestone is found on multiple mounds. Although there is an especially heavy concentration of limestone artifacts on the northeast corner of Mound AB (Trench 39 and Sahni's Trench B), by and large, all types of this material were available to people in most parts of the site.

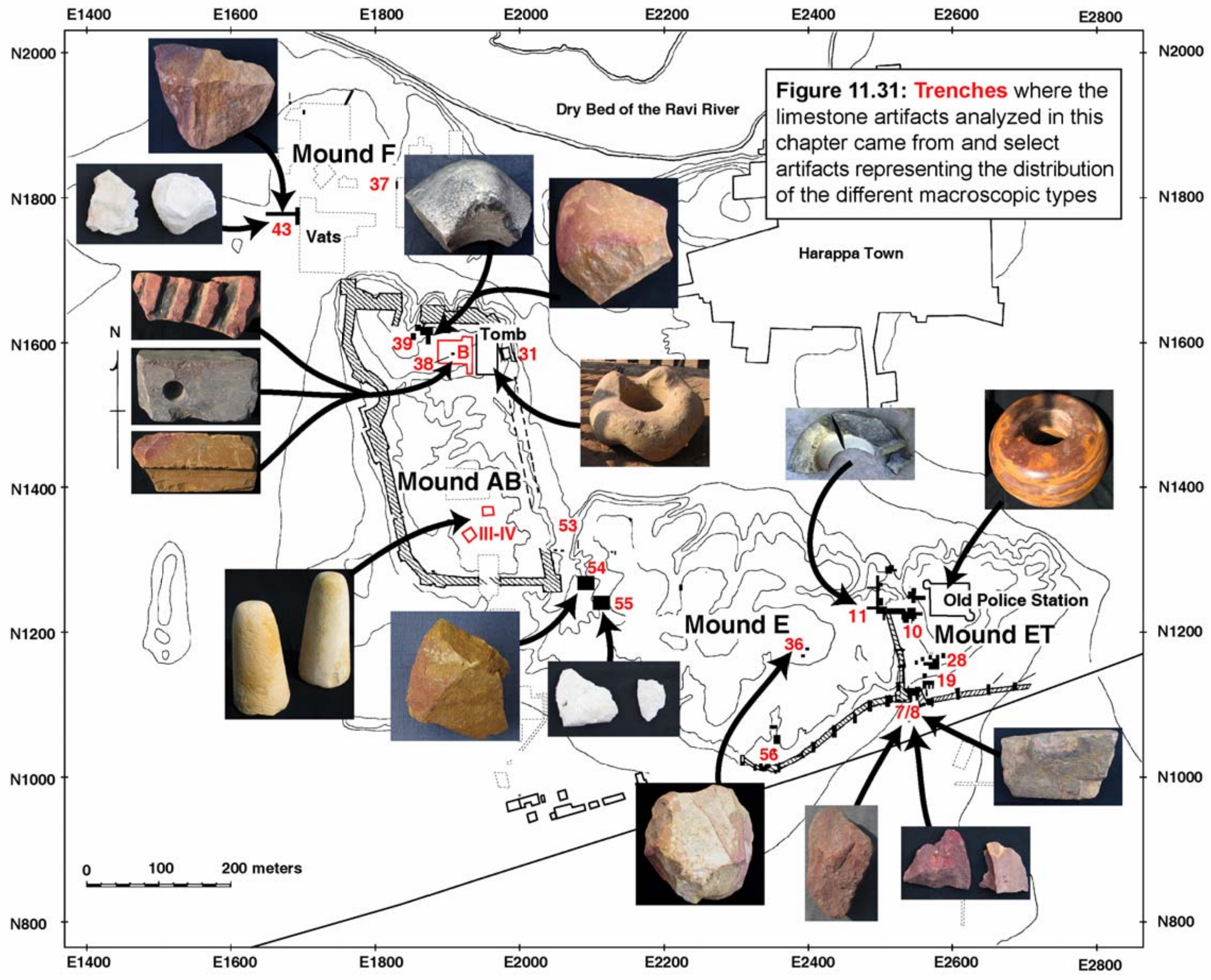


Figure 11.31: Trenches where the limestone artifacts analyzed in this chapter came from and select artifacts representing the distribution of the different macroscopic types

All of the limestone objects analyzed for this study came from either Period 3C deposits or unstratified/disturbed contexts that are most likely representative of Period 3C or later phases. In fact, finds of limestone artifacts of any kind in levels earlier than that are comparatively rare. None are found in the Ravi Phase. A handful of brownish micritic-textured limestone artifacts, including the earliest cubical weight (Meadow and Kenoyer 2001: 26), come from Period 2 levels on Mound AB. The material is absent once again from the rock and mineral assemblage during Period 3A. A dozen fragments, a cubical weight and an inlay of some kind have been recovered from 3B levels in various parts of mounds E and ET. The 250 or so objects making up the remaining portion Harappa's limestone assemblage are mostly large in size and come from deposits that date to Period 3C or later. A group of ringstone fragments and some of the blocks that may be architectural elements were found filling a depression in front of a doorway in Trench 39 together with pointed-base goblets, an association which firmly dates them to Period 3C (Meadow et al. 1998: 6). Although large limestone artifacts have been recovered in these levels across Harappa, it would probably be inaccurate to think of them as being common at that time – at least not in the sense that every Harappan home had a facade of carved limestone blocks or ringstones adorning their entryways. Rather, items made of this stone were likely used to a limited degree for special buildings or in important areas of the site.

Although it is difficult to say precisely where in Harappa's chronological sequence limestone artifacts from past excavations should be placed, most appear to have come from the site's later levels. For example, when excavating the "Granary" area on Mound F, Vats noted that a Jaisalmer stone mace-head recovered there appeared "to have found its way

down from an upper stratum" (Vats 1940: 22). The association of the large limestone objects from Sahni's excavations on the northeast corner of Mound AB with pointed-base goblets definitely dates them to around Period 3C (Vats 1940: 139). Interestingly, at Mohenjo-daro the utilization of limestone for large objects also seems to have been mostly restricted to that site's "Late Period", a time roughly equivalent to the latter part of the urban phase at Harappa. A cache of 18 large limestone ringstones was found in a Late Period side chamber of House V in the HR area (Sahni 1931a: 191) and several more were recovered in the same levels in Area L (Mackay 1931b: 174). Marshall noted that the limestone blocks from the Rohri Hills used for drain covers at Mohenjo-daro, did "not seem to have been introduced before the Late Period" (Marshall 1931c: 31). Even a series of comparatively large stone statues, several of which were made of limestone, came from the later levels at that site (Ardeleanu-Jansen 1984, 1991). It would therefore appear that during the latter part of the Indus Civilization's urban phase (ca. Period 3C at Harappa), limestone began to be utilized at the two largest Indus cities a great deal more than it had been in previous times, especially to create objects that were of larger size than Harappans typical made up to that point. The question then arises – why at that time and not before?

The increased use of limestone at Harappa in the late urban phase cannot be explained by new found access at that time to the source regions examined in this chapter (except *perhaps* Jaisalmer). Evidence presented elsewhere in this dissertation demonstrates that rock and mineral resources were being brought to the site from Gujarat (agate-carnelian), Sindh (chert) and Balochistan (lead) prior Period 3C. Advancements in the ability to transport stone in bulk sizes long distances do not provide a suitable explanation

either. Carts capable of handling heavy loads appear to have existed since the Early Harappan Phase (Kenoyer 2004). The use of watercraft to move heavy loads long distances is implied by the finds of large Harappan black-slipped jars (made at cities like Harappa and Mohenjo-daro and capable of holding 30 to 40 liters of oil, wine or some other substance) at sites across the Arabian Sea in Oman (Méry and Blackman 1999).

Rather than changes in source access or transportation technologies, the evident shift at Harappa (and possibly Mohenjo-daro) in limestone utilization likely had more to do with the nature of this particular material variety in combination with the preferences of those who would use it. Although limestone was widely available across northwestern South Asia, it probably was not used a great deal prior to thelate urban phase simply because, for the most part, it was a material that did not suit the needs of Indus craftspeople or the wants of consumers during earlier periods. Harappans could have easily used it for grindingstones but sandstone-quartzites and igneous rocks were available and are much superior materials for that purpose. Limestone was sometimes used to make cubical stone weights but harder rocks like chert were clearly preferred (≈ 80% of such weights at Harappa are chert – only ≈ 5% are limestone). The reason it was so seldom used to create personal ornaments or other small items probably was because Harappans had access to rocks that were much more durable and/or aesthetically pleasing to them.

On the other hand, limestone is an excellent material to use when making large objects. It tends to break with a conchoidal fracture and is softer than sandstone, quartzite or igneous rocks such as granite or diorite. Thus, objects like ringstones are more easily roughed out and carved from limestone. At the point in time when Harappans began to feel

the need to create larger objects out of stone, it was a natural material for them to choose. Huge formations of limestone were accessible within a distance of 250 km from Harappa in Sulaiman Range and Salt Range and they may very well have used some of the micritic types from those sources. Certain types, although found in more distant locations, were clearly desired for their aesthetic properties just as they are today (e.g. Jaisalmer stone). That different types of limestone from multiple sources were used at Harappa and that some of those sources were quite far from the site simply reflects the great extent of rock and mineral exchange networks in place during Period 3C.

However, the question remains – why, especially if sources were readily accessible and the technologies needed to move heavy stone had long existed, was it not until the latter part of the urban phase (ca. 2200-1900 BC) that large limestone objects began to appear at sites like Harappa and Mohenjo-daro? I believe that this phenomenon probably reflects a new development in the way Harappans (or at least certain Harappans) expressed social power through the consumption and display of stone. Until that point, the creation of small, high-value personal ornaments that signaled the status of those wearing them was one of the principal means through which social and economic hierarchy in the Indus Civilization was marked and maintained (Kenoyer 2000). The wealth-status value of such ornaments is argued to have been largely dependent on two factors – the relative scarcity of the raw materials being used and the level of technological complexity/virtuosity needed to turn them into finished items (Kenoyer 1992a: 45; Vidale and Miller 2000). With bulk stone objects *size* becomes a relevant third factor. A single ringstone weighing 100 kg would have required as much effort, energy and/or expense to bring to Harappa from Kutch

as would 100 kg of high quality carnelian nodules. The difference is that with the nodules hundreds, perhaps thousands, of carnelian beads could have been created and dispersed while with a ringstone all of the effort-energy-expense was concentrated within a single item. Bulk stone objects of this kind thus would have probably been important symbols of wealth, prestige and power for Indus Civilization peoples living at settlements located upon the alluvial plains. Their display may have also been a visible marker of a social or territorial relationship held with the distant region where the stone originated. Using such stones in the construction or adornment of religious spaces, private buildings or public areas such as gateways or streets would have been a powerful expression of a person's, a social group's or an organization's ability to expend energy, wealth or influence (probably all three). The timing of the emergence of this new behavior at Harappa and Mohenjo-daro is interesting as it roughly coincides with other changes seen at those cities during the latter parts of their urban phases such as the widespread use of pointed-base goblets and fluctuations in civic control evident as periods of degrading architecture and poor maintenance of public thoroughfares (Dales 1979: 193-194; Kenoyer 1993: 186-187).

Chapter conclusion

The acquisition and use during Period 3C at Harappa of expensive-to-transport large limestone objects from multiple sources, some as far away at Kutch, represented a new way for Indus Civilization people living there to express prestige and power using stone. In the following chapter, I attempt to identify the geologic sources of various metals – a category of material the use of which may also have been, at times, prestige-related.

Chapter 12

Lead, silver and copper acquisition networks

Chapter 12 – Lead, silver and copper acquisition networks

Chapter introduction – Metals

Of the many rock and mineral varieties found at Indus Civilization sites, archaeologists have by far expended the most time and effort in the study of artifacts made of metals, in particular copper (for recent overviews see Agrawal 2000; Agrawal and Kharakwal 2003; Biwas 1996; Chakrabarti and Lahiri 1996; Kenoyer and Miller 1999). Despite all of the attention, attempts to correlate metal artifacts with their potential sources have been few and limited in nature. Sana Ullah (1940) compared the bulk chemical compositions of copper ores from deposits in Afghanistan and India to copper artifacts from Harappa and suggested that, based on the presence of nickel and arsenic, Harappan copper was probably derived from sources in Rajasthan. Much later Hegde and Ericson (1985) made seven Pb isotope assays on samples of chalcopyrite and galena from deposits in Rajasthan. Although their work was an important first-step for provenience research of this kind, they did not follow up with analyses of additional sources samples or, more importantly, of artifacts that could have been correlated with potential ore sources.

In an effort to advance this line of research another step forward, in this chapter, I compare metal artifacts from Harappa and seven other prehistoric sites to various metal ore deposits in Pakistan, India, Oman and Iran using *lead isotope analysis*. Geologists and archaeologists working in these areas have already isotopically assayed many of the lead, lead-silver and copper sources that would have been accessible to the ancient peoples of these regions. Here, previously published lead isotope data are compiled and presented along with the results of nearly 150 new assays of geologic source samples conducted

specifically for this dissertation. Together, these provide reasonably representative geologic databases, which I use to make provisional geologic provenience determinations for 84 metal artifacts composed of or containing lead. I have determined that, among other things, residents of Harappa acquired lead resources from deposits in at least three regions: Jammu and Kashmir, southern Balochistan and one other source area that has yet to be identified.

I begin this chapter by reviewing some of the forms in which the element lead (denoted by the abbreviation "Pb" – from the Latin "plumbum") is found in both nature and in archaeological materials. A discussion of Pb isotopes and the technique used in this dissertation to sample and measure them follows. Next, an explanation of how isotopic data are evaluated and displayed is provided. At that point, the Pb isotope database for lead deposits is presented in a region-by-region overview of isotopically assayed ore occurrences. After the potential lead sources have been evaluated and readied for comparison, the results of Pb isotope assays made for all of the lead ores, finished artifacts, slags and residues from Harappa are plotted in relation to them and provisional geologic provenience determinations are made. Assays of lead and/or silver artifacts from the sites of Mohenjo-daro, Allahdino, Nagwada, Mehrgarh, Nausharo, Mundigak and Shahr-i-Sokhta are also evaluated in relation to the lead database. Finally, seven archaeological copper ore fragments from Harappa are compared to a second Pb isotope database put together from published data and new analyses of copper ores and slags collected previously unassayed copper deposits. In the conclusion of this chapter, I briefly discuss how these results inform our understanding of the lead, silver and copper acquisition networks in which Indus Civilization peoples, especially those at Harappa, were involved.

Lead, lead artifacts and artifacts containing or derived from lead

Lead, like most other metal elements (gold excepted), is relatively uncommon in its native state and instead is usually found mineralized in sulphide deposits (Rapp 2002: 140). Within those deposits its most common form is the mineral galena – lead sulphide (PbS) (Deer et al. 1992: 604). Galena frequently co-occurs with sphalerite (zinc sulphide) and also sometimes contains significant amounts of copper, silver and antimony (ibid.). Cerussite ($PbCO_3$), anglesite ($PbSO_4$) and massicot (PbO) are all common alteration products of galena and are typically found along the weathered margins (gossan) of lead deposits that are adjacent to calcareous rocks (Guilbert and Park 1986: 811).

Archaeologically, lead has been found in several forms at Indus Valley and Balochistan Tradition sites. Finished items made of this metal include small vessels and utensils, hooks, cones or "plumb bobs," rods, rings and ingots (Francfort 1989: 147-148; Kenoyer and Miller 1999: 119; Mackey 1938: 453; Lal 1985: 656; Ratnagar 2004: 197). Raw, unmodified lead ores of various kinds have been found at several sites as well as lead slags and non-descript lumps (Hargreaves 1929: 33; Mackay 1943: 188; Marshall 1931c: 30). Lead residues that may be the remains of cosmetics or pigments are also known (Sana Ullah 1931: 691).

Even though it is not readily apparent, the element lead is often present in objects made predominantly of other metals. For instance, it occurs as a natural impurity in copper ores such as chalcopyrite (Deer et al. 1992: 595) and copper objects made from such ores usually retain trace amounts of lead. In addition, lead is often deliberately added as an alloy during manufacture of copper alloy items (Agrawal 1971). Metals extracted from lead

ore might also be expected to retain a trace amount of the element. The term *argentiferous* describes metals ores (lead or copper) with a high silver content. Silver artifacts have been found at many Indus Civilization sites and it has often been suggested that much of that metal may have been derived from the smelting of argentiferous lead ores (Asthana 1993: 276; Ratnagar 2004: 193; Pascoe 1931: 675; Sana Ullah in Mackay 1938: 599).

Determining the sources of lead, whether it occurs as a finished item, a raw ore, residue or trace component of an artifact made of another metal like silver or copper, can provide important insights into long-distance acquisition networks in which the residents of Harappa were involved. As is demonstrated below, it is possible to determine the geologic provenience of lead artifacts (and perhaps copper and silver ones too) using lead isotope analysis (Agrawal 2000: 30; Ratnagar 2004: 195).

Lead isotope analysis

The element lead (Pb) has four isotopes (^{208}Pb, ^{207}Pb, ^{206}Pb, ^{204}Pb) that vary in absolute amounts depending on its geologic age and the conditions in which it mineralizes (Guilbert and Park 1986: 286-90). Thus, Pb isotope analysis has long been employed in the geosciences to determine the age and evolutionary environment of ore deposits (Doe and Zartman 1979). This analytical technique has also been effectively applied to the study of archaeological metals over the past 30 years (Lambert 1997: 188-191). The main reason for this is that Pb isotopes do not undergo physiochemical fractionation when an ore is smelted or when the extracted metal is fashioned (and re-fashioned) into finished products (Budd et al. 1995: 127). Thus, an artifact containing lead from a *single* deposit will retain the original isotopic composition of that deposit. Although it is a problematic possibility

that alloyed and/or recycled metal artifacts may contain lead derived from multiple sources, Pb isotope data are, nonetheless, extremely useful for archaeological studies attempting artifact-to-ore source correlation.

Measuring the abundance of the four isotopes of lead within a geologic or archaeological sample is done with a mass spectrometer. Until fairly recently, the majority of Pb isotope analyses were conducted using a thermal ionization mass spectrometer (TIMS) – an instrument which still today produces the most accurate and precise measurements (Pomies et al. 1998). All of the previously published isotope values for geologic samples presented in Appendix 12.1 were made using a thermal ionization mass spectrometer (TIMS). Measuring Pb isotopes using an inductively coupled plasma mass spectrometer (ICP-MS) is, however, becoming increasingly more common (Pollard and Heron 1996). Although the analytical error factor for ICP-MS isotope measurements is somewhat larger than for TIMS, data derived using both techniques can be, and have been, used together effectively (Attanasio at al. 2001; Ingo et al. 1997).

EDTA sampling of lead and silver artifacts and analysis using ICP-MS

The new Pb isotope assays of geologic and archaeological lead and silver samples made for this dissertation were conducted using the ICP-MS at the LARCH. In order to get lead from samples into a liquid solution for analysis, a new technique (Figure 12.1) was used that employs ethylenediaminetetraacetic acid (EDTA) – a hexadentate chelating agent that forms coordinate bonds with lead atoms (Law and Burton 2006a; Reslewic and Burton 2002). A non-toxic sampling solution is prepared that consists of ultra-pure water and 0.05% dissolved EDTA (Figure 12.1 A). A lead artifact that has previously been cleaned

Figure 12.1: A technique for non-destructive Pb isotope sampling and analysis of lead and silver artifacts using ethylenediaminetetraacetic acid (EDTA) and ICP-MS.

A. A non-toxic solution of purified water and 0.05% EDTA is taken to the site or museum at which a lead or silver artifact is stored.

B. The artifact is placed in a small tray; the EDTA solution is poured over it and is then left to sit for two minutes.

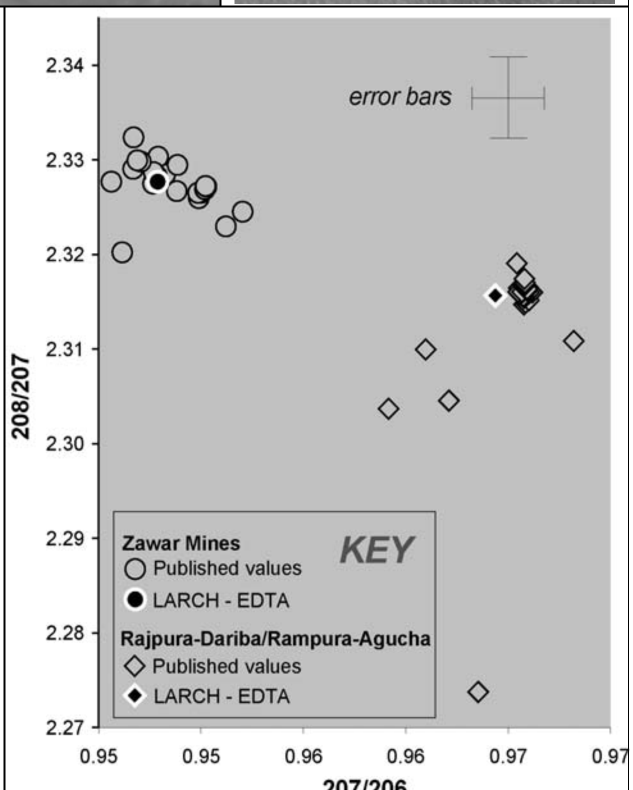
C. The now lead-enriched solution is put into a sample vial and the artifact is washed, dried and returned to the collection.



D. Solutions are analyzed with an ICP-MS. The analytical **precision** (below) of the instrument was determined by repeated measurements of NIST Lead Isotopic Standard SRM 981

	208/207	**207/206**	**207/204**
NIST Standard	**2.3696**	**0.9150**	**15.4970**
mean of 44 measurements	2.3724	0.9157	15.5544
SD of mean	0.004384	0.00175	0.13352
Precision (%RSD)	0.19%	0.19%	0.86%

E. The **accuracy** of this technique was gauged (right) by analyzing ore samples from deposits that had already been well characterized using TIMS. EDTA/ICP-MS derived isotope values for samples from the Zawar and Rajpura-Dariba/Rampura-Agucha lead bodies closely matched previously published (Deb et al. 1989) TIMS data.



in purified water is placed into a disposable plastic sampling tray and approximately 50 ml of the sampling solution is poured into the tray, immersing the artifact (an inscribed lead bar from Harappa [H2000/2174-321] is pictured in Figure 12.1 B). The sample remains in the solution for two minutes while the tray is lightly agitated at 20 second intervals. This short immersion time is sufficient to extract lead from a sample in concentrations from 100 ppb to as much as 100 ppm – orders of magnitude more than minimally required for ICP-MS analysis. After two minutes, the now lead-enriched solution is poured into a sample vial for return to the lab (Figure 12.1 C). The artifact is rinsed in ultra-pure water, allowed to dry and then returned to its place of storage or display. Although this sampling method is technically destructive (Pb atoms form 1:1 bonds with the EDTA and are removed from a sample), the short immersion time in the sampling solution does not result in any macroscopic alteration of lead or silver artifacts whatsoever.

Lead-enriched solutions sampled from archaeological and geologic materials (sites and locations to be discussed) were returned to Madison and analyzed on the ICP-MS in groups of five. For accurate counting statistics, 10^7 counts per second (approx. 10 ppb) were required against a background of approximately 10^4 counts per second. An EDTA-sampled solution of the NIST Common Lead Isotopic Standard (SRM 981) was assayed before and after each group run. Based on repeated measurements (n=44) of this standard, the overall *precision* (Figure 12.1 D) – an expression of analytical error based on the relative standard deviation (%RSD) of all of those measurements, was calculated to be under 0.2% for ratios constructed (discussed below) using the isotopes ^{208}Pb, ^{207}Pb and ^{206}Pb. It was significantly higher (0.86%) for ratios using ^{204}Pb. Although considerably less precise than TIMS, which

typically produces measurements with a precision of 0.005 to 0.01 %RSD (Heumann et al. 1998), the ICP-MS has, nonetheless, provided values (for all ratios except those using ^{204}Pb) for which it is possible to be confident of to at least three significant digits. Furthermore, the frequently assayed NIST standard has been used to adjust (correct) measured isotopic values on the samples to more accurately reflect what their true values likely are. This was done by taking the average of the values measured for the two bracketing standards (one run before and one after five samples), calculating how that average varied from the set NIST standard and then adjusting the measured values on the samples by the difference.

In order to gauge the accuracy of this technique and the corrections applied to the data it provided, one galena sample each from two isotopically well-characterized lead occurrences in southern Rajasthan – Zawar and Rajpura-Dariba/Rampura-Agucha, was analyzed using the EDTA/ICP-MS method. The data were compared to the published TIMS produced values from those two ore fields (Deb et al 1989). In both cases, the corrected EDTA/ICP-MS isotopic values for the geologic test samples closely matched those of the highly accurate TIMS method (Figure 12.3 E).

Although not as precise as TIMS, there are many advantages to using a combination of EDTA sampling and ICP-MS for the analysis of lead artifacts. Sampling using this technique is, for all practical purposes, non-destructive. No material need be chipped off or scraped from an artifact for digestion in acid. Although EDTA sampling is “destructive” in the sense that some Pb ions are physically removed from the surface of the sample, this only takes place at an atomic level. Macroscopic alteration of artifacts is in no way evident. Ease, speed and cost of sample preparation and analysis are other advantages.

Preparing lead samples for TIMS is an extended and laborious process that results in such analyses being quite expensive and time consuming. The EDTA/ICP-MS method is considerably less difficult and comparatively less expensive. No hazardous acids or purification columns need be used. The simple and short sample preparation process and the ease of ICP-MS (as compared to TIMS) help keep the cost of isotopic analysis using this method reasonably low. A final advantage is that artifacts sampled for Pb isotopes in this way need not be removed from location at which they are stored. A small kit containing purified water (for artifact cleaning before and after sampling), the non-toxic EDTA solution, disposable containers (for artifact immersion in the solution) and vials (for holding the sampled solution) can be taken directly to a site being excavated or a museum collection and lead artifacts can be quickly and easily sampled.

Presenting and plotting Pb isotope data

Lead isotope data are normally presented as ratios of the absolute amount of one isotope against the absolute amount of another – for example $^{208}Pb/^{204}Pb$. Although only three *distinct* ratios can exist (as there are only four isotopes of lead), a dozen variations are possible depending on how one chooses to construct them. Those chosen to be presented often vary from publication to publication. Three ratios ($^{208}Pb/^{207}Pb$, $^{207}Pb/^{206}Pb$ and $^{207}Pb/^{204}Pb$) are reported in the various appendices for this chapter. If future users of this data wish to employ combinations not presented here it is possible to easily extrapolate them from the ratios provided. For example, the ratio $^{206}Pb/^{204}Pb$ may be generated simply by dividing the ratios $^{207}Pb/^{204}Pb$ by $^{207}Pb/^{206}Pb$. In the course of compiling the databases in this chapter, extrapolation was used when published isotope ratios were different from

the three selected to be presented here. *Caution is advised*, however, when constructing any ratio using ^{204}Pb from a sample analyzed at the LARCH, as measurements made for that isotope are significantly less precise than those made for ^{208}Pb, ^{207}Pb and ^{206}Pb.

Pb isotope data are graphically represented on a bivariate plot of the values for two ratios. Since three distinct ratios exist, two such plots are required to fully display all measured data (Weeks 2004: 131). However, only one plot is used in this chapter (with ^{208}Pb/^{207}Pb for the *y* axis and ^{207}Pb/^{206}Pb for the *x* axis) because of, once again, the imprecision of the ^{204}Pb values for samples analyzed at the LARCH. Although omitting the third dimension by dropping ^{204}Pb does, admittedly, create some limitations, it does not necessarily impede one's ability to discriminate between lead sources and/or to make provenience determinations. Klein and others (2004) were able to differentiate Roman lead and copper sources without using ^{204}Pb data. In fact, when Sangster and others recently (2000) compared Pb isotope data from 151 lead deposits around the world, they found that:

> Statistical analyses suggested that while ^{204}Pb is critical for identifying a small proportion of environmental Pb sources, about 86% of the source discrimination power is due to the ^{206}Pb, ^{207}Pb, and ^{208}Pb isotopes. Thus, the requisite analytical precision, rather than a lack of ^{204}Pb data, is the most critical issue with respect to unequivocal identification of Pb sources in most cases (Sangster et al. 2000: 115).

For this study, very good analytical precision overall measuring ^{206}Pb, ^{207}Pb and ^{208}Pb was achieved using the EDTA/ICP-MS technique. I will show that convincing statements regarding the probable geologic proveniences of metal artifacts from Harappa and other sites can be made based a single plot generated using those three Pb isotopes alone.

Lead and silver

Sir Edwin Pascoe, who was Director of the Geological Survey of India during the 1920s, noted that "with the exception of iron, there is perhaps no metal whose ores appear to have been worked to so large an extent in India as those of lead" and added that much of the emphasis in the exploitation of this mineral was directed toward the "extraction of silver" (Pascoe 1931: 676). Yet instead of focusing on sources in northwestern South Asia, he mentioned locations stretching from Burma to Tunisia where these metals are found (ibid.: 675-677). Although some of the places he listed are adjacent to the Indus Basin and would have been, more or less, accessible to Harappan consumers, most of the regions he states "might be looked upon as possible sources" (ibid.: 675) of lead and silver are located in South India, Afghanistan, Iran, Burma and even Armenia!

It is somewhat mystifying as to why Sir Edwin largely ignored (and presumably felt that Harappans would have ignored) the deposits of lead and lead-silver that practically ring the Indus Basin (Figure 12.2). In the intervening years some scholars have recognized the importance of these indigenous sources (Agrawal 2000; Chakrabarti and Lahiri 1996) and, in some areas, have even conducted detailed studies of ancient mining and production (Craddock et al. 1989). Others, however, still repeat (almost verbatim) what Pascoe wrote 75 years ago (Asthana 1993; Biwas 1996). Although I do not ignore the possibility that metals like silver were imported from sources far outside of the Greater Indus region (Ratnagar 2004: 199), here I emphasize the isotopic characterization and comparison of lead and silver deposits in closer areas where they were more "easily procurable" (Chakrabarti 1990: 143).

The Pb isotope database of potential lead and silver sources

The Pb isotope database for lead deposits assembled here (Appendix 12.1) consists of 211 analyses made on lead ore samples from 45 individual localities throughout India, Pakistan and Oman (Figure 12.2 and 12.3). One hundred thirteen of those isotopic determinations were drawn the geologic literature. Ninety-eight new Pb isotope analyses were conducted at the LARCH on samples from previously uncharacterized (or under-characterized) lead and lead-silver deposits in Gujarat, Rajasthan, Uttaranchal, Himachal Pradesh, Jammu and Kashmir, and Balochistan. Not included in the primary database are seven assays of lead slags (and a few ores) from the argentiferous galena deposit at Nakhlak, in central Iran (Appendix 12.6), which are considered only in examinations of lead and silver artifacts from sites in Iran (Shahr-i-Sokhta) and Afghanistan (Mundigak).

In the following sub-sections, potential lead and lead-silver sources are discussed on a region-by-region basis, as are important deposits that have yet to be characterized and, importantly, the ancient cultures and settlements located in those regions that Harappans would have almost certainly been directly or indirectly interacting with in order to obtain this mineral resource.

Lead deposits in Balochistan

In Pakistan's Balochistan Province, lead occurs at multiple locations within the Las Bela, Khuzdar and Chagai districts (Ahmad 1975: 63-65; Shams 1995b: 246-47). During the latter half of the third millennium BC, both Indus Civilization settlements and those belonging to the local Kulli culture, which possessed a great many traits that are considered to be typically "Harappan," could be found in the area of southeastern Balochistan



Figure 12.1: Isotopically assayed lead ore deposits of the Greater Indus Valley Region. Sites from which lead or silver artifacts were analyzed for this study are in **red**.



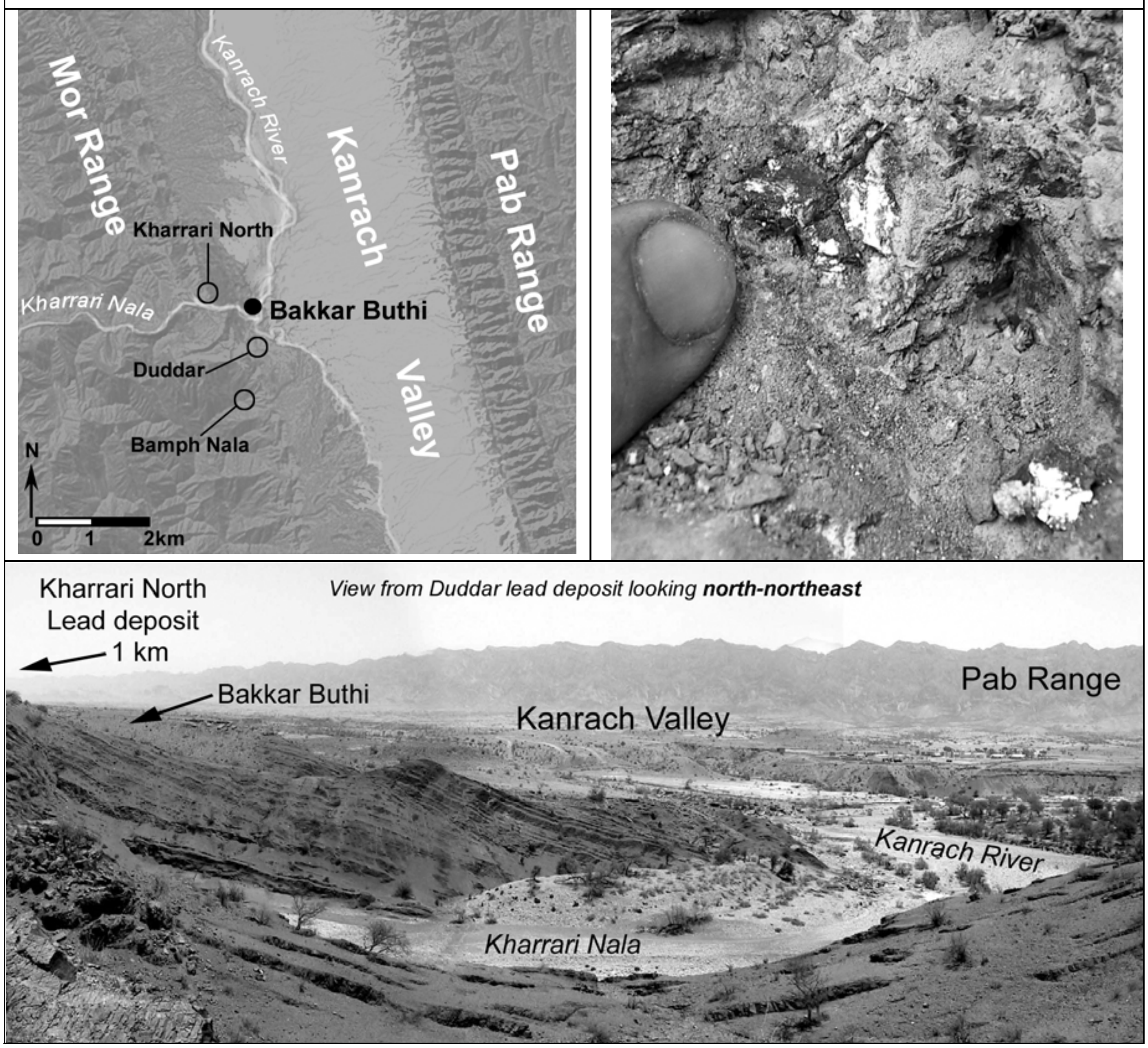
Figure 12.2: Isotopically assayed lead sources outside of the greater Indus Valley region.

encompassed by the former two districts. Although it remains to be determined if it is appropriate to characterize Kulli society as "the highland form of the Indus Civilization" (Possehl 1986: 61), it seems evident that there was a high degree of interaction taking place at this time between those dwelling in this region and the Indus Valley. The lead sources of southern Balochistan, therefore, would have likely been among the most accessible to Indus Civilization consumers. Somewhat less accessible, but still important, would have been the deposits in the Chagai district, which are located along what would have been one of the major trade and communication routes between the Indus Valley and southwestern Afghanistan and eastern Iran.

Lead mineralization can be found at several places in the Las Bela district (Ahsan and Bhutta 1991; Heron and Crookshank 1954: 93) but the largest and most economically viable deposits occur in the central part of the north-to-south running Kanrach Valley (Figure 12.4). Isotopic analyses of four galena samples from the Duddar and Kharrari areas (N 26° 05' 33", E 65° 50' 16") had been undertaken prior to this study (Bhutta 1992; Siddiqui 1994, Bhutta and Qureshi 1997). Twelve additional assays were performed at the LARCH on samples collected in May 2001 from the Kharrari North area and a third location in nearby Bamph Nala. It is especially important to note that all of these locations are found within one to two kilometers of the prehistoric site of Bakkar Buthi, which contains both Kulli and "purely Harappan" occupation levels (Franke-Vogt et al. 2000: 196). A.H. Kidwai (in Heron and Crookshank 1954: 93) reported "weathered ore, slags of lead and copper, [and] furnace clay" at a location noted at "ruins" (near Thana Kanrach) around 20 km to the north of the site. Although no such items were found during the

limited excavations at Bakkar Buthi (Ute Franke-Vogt *personal communication* 2003), it is by far the nearest of all Harappan settlements to a source of lead.

Figure 12.4: [*top left*] Map of central Kanrach Valley and lead deposits sampled for this study. [*top right*] Galena at Bamph Nala. [*bottom*] Area around Bakkar Buthi.



Lead in the Khuzdar district (formerly part of the Kalat district) occurs at several places in the vicinity of Khuzdar town including Gunga, Shekran and Surmai (Ahmad 1975: 64; Jankovic 1986; Shams 1995b: 246; Siddiqui and Sharp 1993). Shams noted (1995b: 246) that the ore at Gunga (N 27° 44' 30", E 66° 32') was highly argentiferous,

containing up to 3000 ppm silver (recall that 10 ppm is considered viably argentiferous – Craddock 1995: 211). Three isotopic analyses of galena samples from that deposit were performed by Siddiqui (1994). Two additional samples from this location were supplied by Drs. Mehrab Khan and Khalid Mahmood of the University of Balochistan - Quetta and analyzed at the LARCH. Numerous old mines and slag fields have been noted throughout this part of the Khuzdar district (Hassan 1989; Heron and Crookshank 1954: 92; Siddiqui and Sharp 1993). All are located within 25 km of the ancient mounds at Sohr Damb (Nal), where galena, cerussite, lead slags and silver artifacts have been recovered (Hargreaves 1929: 33). Importantly for this study, a "Kulli-Harappan" presence dating to the latter half of the third millennium BC has recently been documented at that site (Franke-Vogt 2000).

Although rich and extensive polymetallic sulphide deposits are found in the northwestern part of the Chagai District (Ahmad 1975; Shams 1995b: 243-247), showings of galena tends to be minor in nature (Kazmi and Jan 1997: 449). Nevertheless, Pb isotope assays were made at the LARCH on a total of 12 galena samples from deposits at Koh-i-Sultan (≈ N 27° 07', E 62° 47') and Rekodiq (≈ N 29° 10', E 62° 14'), which were supplied by Drs. Mehrab Khan and Khalid Mahmood of the University of Balochistan – Quetta.

Lead deposits in the NWFP

Lead ore in Pakistan's North-West Frontier Province (hereafter NWFP) is found primarily in the Chitral, Allai Kohistan, Swat and Hazara districts (Ahmad 1969: 39-40; Shams 1995b: 245-46). There are several reasons to believe that Harappans may possibly have obtained this metal from deposits in these districts. Numerous Early Harappan period (Kot Dijian) sites can be found in or directly adjacent to the southern parts of the province

(Allchin 1984). Also, the most direct route to Shortughaï, the Indus Civilization outpost in northern Afghanistan (Francfort 1984b), would have been through the NWFP. Lastly, but certainly not least, I have already show in this dissertation that two other important varieties of stone – steatite (Chapter 7) and vesuvianite-grossular garnet (Chapter 9), seem to have been acquired from sources located in this region.

Lead mineralization, sometimes co-occurring with copper and antimony, has been noted at nearly a dozen locations in the southern part of the Chitral district (Ahmad 1969: 39-40). Tahirkheli and others (1997) performed Pb isotope analysis on three galena samples from a zone of copper mineralization in the Shi Shi Valley area near Drosh (≈ N 35° 39', E 71° 54'). Farther to the southeast, five Pb isotope determinations were made by Shah and others (1992) for the Lahor and Pazang lead deposits in the Besham area (≈ N 34° 56', E 72° 52'), Allai Kohistan.

Among the lead sources in the NWFP that have not yet been isotopically assayed are those near Ushu (N 35° 34', E 72° 43') in the Swat district (Tahirkheli 1959) and several zones of galena mineralization around the Abbottabad area (≈ N 34° 11', E 73° 03'), Hazara district (Shams 1963; Ahmad 1969: 40). It will be especially critical to acquire material from these sources for future analysis. Early Harappan period interaction with the Swat region is suggested by finds of Kot Dijian-like ceramics at Ghalegay Cave (Stacul 1987: 29-49). The Kot Dijian sites of Sarai Khola, Hathial and Jhang (Khan 1983; Halim 1972) lie around 50 km or so south of the Hazara district galena sources, which themselves are situated within a few kilometers of the steatite deposits shown (Chapter 7) to have quite probably been the major source of that material for residents of Harappa.

Lead deposits in Jammu and Kashmir

In the Jammu and Kashmir region, lead mineralization occurs in the districts of Doda, Riasi, Baramulla, Anantnag and Muzaffarabad (Ahmed 1997; Srivastava 1977; Varadan 1977: 52-54). The geologist C.S. Middlemiss noted (1929: 2) that the "lead-silver deposits of the State [*appear to*] have been worked in a primitive way during ancient times." Importantly, some of these deposits are located (Figure 12.5) in the vicinity of Indus Civilization settlements and/or along the natural routes through which Northern Neolithic and Kot Dijian/"Late" Kot Dijian phase peoples interacted with one another.

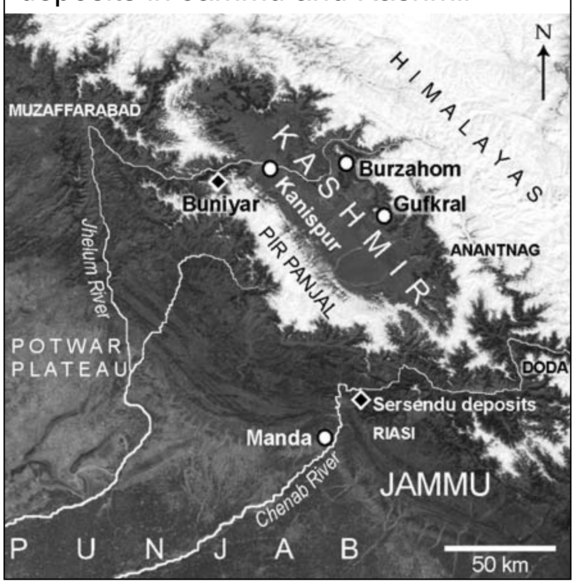


Figure 12.5: Select sites and lead deposits in Jammu and Kashmir

Sporadic occurrences of lead-zinc are found within the Great Limestone formation of the Riasi district (Nayak and Sharma 1991). Four galena samples from abandoned workings near Sersendu village (N 33° 06' 53", E 74° 54' 00") were isotopically assayed by Raha and others (1978). Additional assays were made at the LARCH on 11 samples from this same area. I collected six of those from an old mine at nearby Kheri Kot in June of 2003. Five more were provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology who collected them from the nearby Darabi area. These deposits are the closest lead sources to Harappa and are located less than 30 km north of Manda, where Joshi and Bala (1982) identified both Early Harappan and Harappan occupational phases.

In the Baramulla district, lead can be found at various places in the Buniyar area along Hapatkhai Nala (≈ N 34° 06', E 74° 12'), about a kilometer south the Jhelum River (Middlemiss 1929; Raina 1977). The Jhelum River is an important route connecting the Kashmir Valley to the Potwar Plateau and upper Indus Basin. The cache of carnelian beads in a Kot Dijian style pots recovered at the Northern Neolithic site of Burzahom (Pande 2000) provides clear evidence for interaction and exchange between the ancient peoples of those regions. Lead from the Buniyar area, which sometimes contains minor amounts of sphalerite and chalcopyrite in addition to galena (Sharma and Sachan 1998), could have been an important trade good for Northern Neolithic Phase Kashmiris, who were settled as near as 20 km to the northeast at Kanispur (Mani 2000). Pb isotope determinations were made at the LARCH on seven galena samples from the Buniyar occurrences provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology at Dehra Dun.

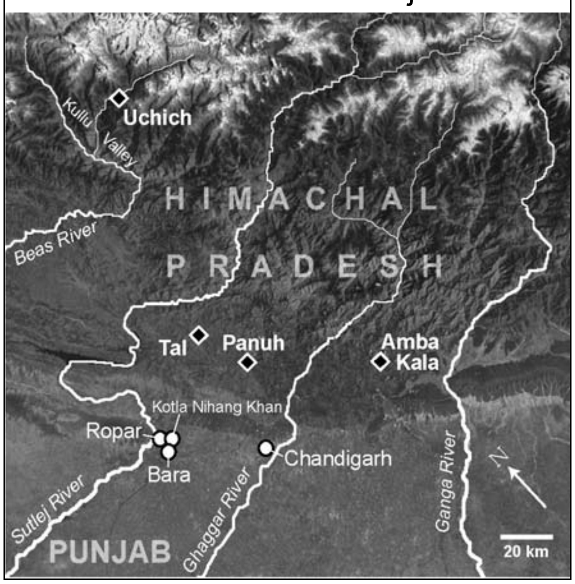
Several lead sources in Jammu and Kashmir have yet to be isotopically characterized. At Treri (N 34° 26' 48", E 73° 43' 10") in the Muzaffarabad district, galena is found with zinc and copper (Ahmad et al. 1992; Ahmed 1997). Nodules of galena can be found at Hapatnar (N 33° 50', E 75° 21') and Shumahal (N 33° 50', E 75° 17') in the Anantnag district (Varadan 1977: 52). In the Doda district, galena and cerussite are found near Chichhe village as are old workings for those minerals (Srivastava 1977).

Lead deposits in Himachal Pradesh and Uttaranchal

D.P. Agrawal argued (1999) that the central Himalayas were an important, but largely overlooked, region with regard to the study of South Asian archaeometallurgy. Indeed, the states of Uttaranchal and Himachal Pradesh are exceptionally rich in both base

and noble metals. Geologists have noted the existence of scores of disused mine shafts, pits, slag heaps and waste dumps that indicate the varied deposits of the region were widely exploited in former times (Sharma 2002). Ropar, Bara and Kotla Nihang Khan are all proto-historic settlements found within 10 km of the point near which the Sutlej River leaves the foothills of the lesser Himalayas (Sharma 1982). Harappan period remains were also unearthed at Chandigarh, not far from where the Ghaggar River meets the plains (Joshi 1990: 15). Indus Civilization peoples dwelling at any of these sites would have been well positioned (Figure 12.6) to access the rich lead-silver deposits of the central Himalayas.

Figure 12.6: Select lead deposits in Himachal Pradesh and Punjab sites



In Himachal Pradesh, lead deposits occur in the Kinnaur, Kullu, Simla and Sirmaur districts (Chowdhury and Sehgal 1962; Geological Survey of India 1989a: 32-33; Srikkantia and Bhargava 1998: 335-36). Prior to this study, no Pb isotope determinations had been made for any of the deposits in the state, many of which are highly argentiferous. The lead mines in the Kullu Valley and others adjoining it have long been famous as sources of silver (Calvert 1873). Five Pb isotope determinations were made on samples collected in June of 2004 from the old silver mine at Uchich (N 32° 00' 41", E 77° 22' 27") near Manikaran in the Parvati Valley, Kullu (formerly Kangra) district (Sehgal 1964). Samples were also collected at that time from the galena mines at Panuh (N

30° 58’ 12”, E 77° 01’ 15”) and Tal (N 31° 09’ 57”, E 76° 57’ 18”) in the Solan district (Chattopadhyay and Verma 1992; Kumar 1992). Ten Pb isotope analyses for the Panuh deposit and five for the Tal deposit were conducted at the LARCH. Galena at Amba Kala (N 30° 38’ 29”, E 77° 27’ 24”) in the Sirmaur district is reported to contain up to 250 ppm silver (Geological Survey of India 1989a: 49). Five Pb assays were made on samples collected from that deposit in May of 2003.

Although lead mineralization occurs across Uttaranchal, the richest deposits are found in the eastern portion of the state in the Kumaun region (Valdiya 1980: 263). Many of these deposits are highly argentiferous, such as the one near Birgana village, Garwal District (Shrivastava and Kapoor 1981). Sarkar and others (2000) assayed three galena samples from the lead-copper deposits found in the vicinity of Bageshwar (≈ N 29° 48’, E 79° 46’) (Banerjee 1977; Srivastava and Gaur 1979). Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology, Dehra Dun supplied galena samples from two additional Kumaun region deposits for Pb isotope analysis at the LARCH. Three samples were from the polymetallic sulphide deposit at Askot (≈ N 29° 46’, E 80° 20’) in the Pithoragarh district near the border with Nepal (Acharya 1988; Ghose 1976). Two samples came from an area of galena mineralization at Khansue, Okhalkanda subdivision, Nainital district.

Lead deposits in Rajasthan and Gujarat

The base metal deposits of Rajasthan are extensive and numerous. There is evidence they were exploited beginning at least as far back as the Early Historic period of South Asia. Lead mineralization can be found in the Udaipur, Rajsamand, Bhilwara, Sirohi, Ajmer, Sawai Madhopur, Chittorgarh, Pali, Banswara and Bharatpur districts

(Geological Survey of India 1994; Indian Bureau of Mines 1995: 29-38). In this section, only those deposits that have been isotopically characterized are discussed.

The Khetri copper belt is the dominant zone of sulphide mineralization in northern Rajasthan (Geological Survey of India 1994: 2-34) and was almost certainly a major source of that metal during the Harappan period (Agrawala 1984). Sites belonging to the Ganeshwar-Jodhpura culture complex are found across this region. Stylistic analyses of copper arrowheads suggest that there were contacts between peoples of that phase and Harappans (Rizvi 2007: 152). However, is unlikely that much, if any, of the raw lead used by Indus Civilization peoples was derived from northern Rajasthan sulphide deposits. The only location where galena mineralization can be found in the Khetri copper belt is on its southern margins at Saladipura (N 35° 34’, E 72° 43’) in the Sirohi district. There it occurs in trace amounts together with sphalerite and pyrite (Das Gupta 1970). Two Pb isotope analyses of galena from this location were conducted by Deb and others (1989).

Although the zone of mineralization is largely obscured under the alluvium, “extensive old workings for galena” are still evident at Chauth-ka-Bawara (N 26° 02’ 59”, E 76° 11’ 05”) in the Sawai Madhopur district (Geological Survey of India 1994: 135) of eastern Rajasthan. Five galena samples collected from this deposit in June of 2004 were analyzed at the LARCH.

The largest concentration of lead deposits in this database is situated in the southern Rajasthan / northern Gujarat area. A supplementary map (Figure 12.7) is provided for the discussion of potential sources in this region. Individual locations in the Ambaji-Sendra sulphide belt are identified as well as important Harappan and Ahar-Banas complex sites.

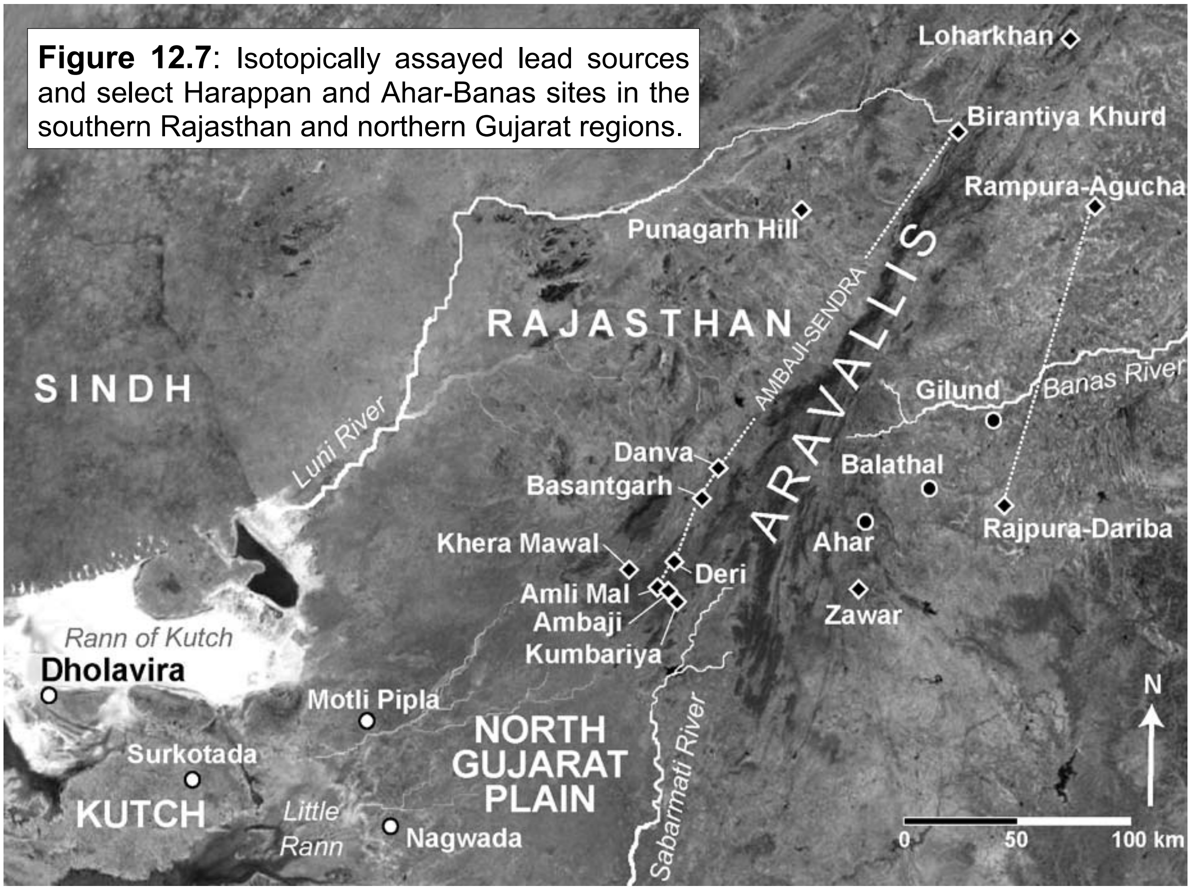


Figure 12.7: Isotopically assayed lead sources and select Harappan and Ahar-Banas sites in the southern Rajasthan and northern Gujarat regions.

Lead occurs at numerous locations within the Ajmer and Pali districts of central Rajasthan (Geological Survey of India 1994: 53-62). Old workings are found (N 26° 29' 08", E 74° 39' 10") on the outskirts of Ajmer city at Lohakhan (Nath 1972). One sample collected at this location in January of 2004 was analyzed at the LARCH. Abandoned mine shafts penetrating as deep as 40 m can be seen at Punagarh Hill (N 25° 48', E 73° 26') in the Pali district (Gupta 1977; Sahai et al 1997: 180). Two galena samples from this location were analyzed by Deb and others (2001).

The lead deposits of the Udaipur, Rajsamand and Bhilwara districts of Rajasthan are the richest in India and the most isotopically well characterized. Twenty-one Pb isotope determinations have been made (Balasubramanyan and Chandy 1976; Deb et al.

1989) on galena samples from the lead-zinc deposit at Zawar (N 24° 20’, E 73° 41’) in the Udaipur district. Evidence suggests that mining and beneficiation of ores from this deposit began around 2000 years ago (Freestone et. al 1985; Craddock et al 1989). Collectively there have been 31 isotopic determination made (Balasubramanyan and Chandy 1976; Deb et al. 1989; LARCH 2004) on galena samples from the Rajpura-Dariba lead belt (≈ N 24° 38’, E 74° 18’) in the Rajsamand district and the Rampura-Agucha deposit (N 25° 49’, E 74° 43’) in the Bhilwara district. Occurring in the same geologic terrain, these two zones of polymetallic sulphide mineralization are isotopically indistinguishable and so are treated as a single source in this study. The lead from both the Rajpura-Dariba and Rampura-Agucha deposits is richly argentiferous (Mukherjee et al. 1991; Lahiri and Ravindranath 1988) and there is evidence for mining, smelting and/or silver cupellation at those locations extending as far back as the mid-second millennium BC (Willies 1989). If it is could be shown that Indus Civilization peoples might have obtained some of their lead and/or silver from these sources then it would provide compelling evidence of long-distance interaction with peoples belonging to early phases of the Ahar-Banas culture of southern Rajasthan (Chakrabarti 1968; Fairservis 1975: 335-340; Shinde et al. 2005).

In the Sirohi district near the border with Gujarat, pockets of galena are found at Khera Mawal (N 24° 24’ 37”, E 72° 42, 46”) intermittently along a 500m zone (Geological Survey of India 1994: 68). Deb and others (2001) produced a single isotope determination for a galena sample from this location. Data for four additional samples was produced at the LARCH after the deposit was visited in January of 2004 specifically for this project.

Beginning on the northern border of Gujarat at Ambaji and extending approximately 240 km into southern Rajasthan near Sendra is a geologic terrain that contains many areas of massive sulphide mineralization (Deb et al. 2001). Old workings, mine dumps and slag fields are noted at numerous locations across this zone (Murty and Shekar 1975: 32; Sahai et al 1997: 182; Geological Survey of India 1994: 34; *personal observations*). Sixteen Pb isotope determinations in total have been made (Deb et al. 1989; Deb et al. 2001; LARCH) on ore samples from following locations within the Ambaji-Sendra sulphide belt: Ambaji (N 24° 20' 43", E 72° 50' 48"), Amli-Mal (N 24° 21' 53", E 72° 48' 22"), Kumbariya (N 24° 18' 36", E 72° 53' 48"), Danva (N 24° 46' 10", E 73° 02' 10"); Deri (N 24° 20' 43", E 72° 50' 48"), Basantgarh (N 24° 43' 30", E 73° 01' 15") and Birantiya Khurd (N 26° 07', E 74° 08'). The Indus Civilization peoples at sites like in north Gujarat like Dholavira or Nagwada might have accessed these deposits directly or via interaction with hunter-gatherer groups of the North Gujarat Plain (Possehl 1980: 73).

Lead mineralization is much more minor in nature elsewhere in Gujarat. The sporadic occurrences that do exist, however, could conceivably have been exploited by the Harappan or related cultures of the region (Ajithprasad 2002; Possehl 1980, 1992; Sonawane 2002). A small deposit of galena is located near Khandia (N 22° 19' 26" E 73° 33' 39") in the eastern part of the Vadodara district (Shah et al.1985; Yellur 1969). Five isotopic analyses of samples collected from this deposit in May of 2003 were performed at the LARCH. In the Junagadh district of southern Saurashtra, galena together with specks of chalcopyrite (Shekar and Mukul 1969) is found in the Gir Forest near Banejnes (N 21°

03’ 15”, E 70° 53, 48”). Five isotopic analyses of samples collected from this deposit in May of 2003 were performed at the LARCH.

Lead deposits elsewhere in South Asia

In this section, I briefly review Pb isotope analyses of galena from deposits in South Asia that are either minor in nature or not encompassed by the current study area – the Greater Indus region. Although many of these deposits were probably not utilized by Harappans, in the interest in producing a comprehensive database, these data are included in the appendix and plotted on the accompanying charts.

Deb and others (2001) made a single Pb isotope determination on galena from the polymetallic ore deposit at Tosham Hill (N 28° 52’ 32”, E 75° 54’ 41”), district Bhiwani, Haryana. This deposit has been proposed as a possible source of tin for the Indus Civilization (Kochhar et al. 1999). However, only trace amounts of galena occur with the other metals found there (Awasthi et al. 1981). Although Tosham Hill cannot be ruled out as a source of Harappan lead, it is unlikely that any galena was extracted from this location.

In total, 15 Pb isotope analyses have been made on galena samples from deposits in eastern India. In the state of Bihar, three isotope determinations exist for the lead deposit at Amjhor (Balasubrahmanyan and Chandy 1976) and five for those in the Hesatu-Pindura sulphide belt (Singh et al. 2001). Three samples from Gorubathan, West Bengal and four from Rangpo, Sikkim have also been analyzed (Sarkar et al. 2000). All of these deposits are over 800 km away from the easternmost Harappan site. It seems highly unlikely Harappans would have exploited these sources when much closer ones were at hand.

Lead deposits in Oman and Iran

One area outside of the Greater Indus region that was evidently visited by Indus Civilization peoples is the eastern part of the Arabian peninsula. Harappan artifacts have been recovered at a number of coastal and inland sites located present-day Oman and the United Arab Emirates (Cleuziou 1984, 1992; Cleuziou and Vogt 1985). Part of the impetus for Indus peoples to make such a distant journey may have been the acquisition of metals, in particular copper, from the region's rich sulphide deposits (Weisgerber 1984). However, although a great deal of Pb isotope data exists for that region, most of the analyses made to date have been conducted on pyrite, chalcopyrite or various volcanic rocks (Calvez and Lescuyer 1991; Chen and Pallister 1981). Only three of the Pb isotope determinations presently available were conducted on galena samples from lead deposits: Wadi Mayh (≈ N 23° 25' 53", E 58° 33'), Qumayrah (N 23° 55' 57", E 56° 11' 42") and a section of the Semail ophiolite near Ibra (N 22° 41' 25", E 58° 32' 04").

The metalliferous ore deposits of Iran are numerous and widespread but nowhere are they richer or more varied than in the Central Persian Desert (Wertime 1968). "At Anarak-Nakhlak nearly all the minerals of the desert come together in a remarkable and evident juxtaposition; thus this region was one of the earliest homes of metallurgy anywhere in the world" (ibid.: 927). The argentiferous lead deposit at Nakhlak (N 33° 33' 50", E 53° 50' 40"), which have been assayed at silver 715 grams per ton, appears to have been worked since ancient times (Holzer and Ghasemipour 1973). Stos-Gale (2001) published the results of Pb isotope analyses on slags and ores collected from this deposit, the values of which have been extrapolated for use in the present study (Appendix 12.6).

Afghanistan

Referring back for a moment to Figure 12.2, it is plain to see that Afghanistan is a conspicuous "hole" in this dataset that, although not comprehensive, is otherwise reasonably representative of the different regions immediately surrounding the Indus Basin where Harappans might potentially have acquired lead or silver (if extracted from lead). There are five major lead deposits and nearly 100 more documented occurrences and showings of that metal throughout Afghanistan (ESCAP 1995: 30). One of the more important sources in terms of this study is the Asad Qala (Kalai-Assad) deposit (Berthoud et al. 1977; Jarrige and Tosi 1981), which is around ten kilometers north of the Helmand Tradition site of Mundigak (Casal 1961). Isotopic assays have been made for a series of lead and silver artifacts from Mundigak and are presented below. Until geologic materials from Asad Qala can be analyzed, those artifacts may serve as proxy samples for that deposit (of course, I am making the assumption that the metal was locally procured).

Plotting and evaluating the Pb isotope data for South Asian lead deposits

When the 211 Pb isotope determinations comprising the lead deposits database are placed on a bivariate plot, the majority (196) of samples cluster into a loose linear pattern (Figure 12.8). Fifteen samples from three lead sources (Banejnes, Uchich and Besham) are isotopically distant outliers (Figure 12.9) to the main body of lead deposits. Although there is a degree of overlap between many of the individual deposits and ore fields, by and large, most major lead sources are isotopically distinct from one another – especially a when considered at a regional scale. For example, most of the lead deposits of Rajasthan cluster in the lower right area of Figure 12.8. The Ambaji-Sendra belt, which extends from

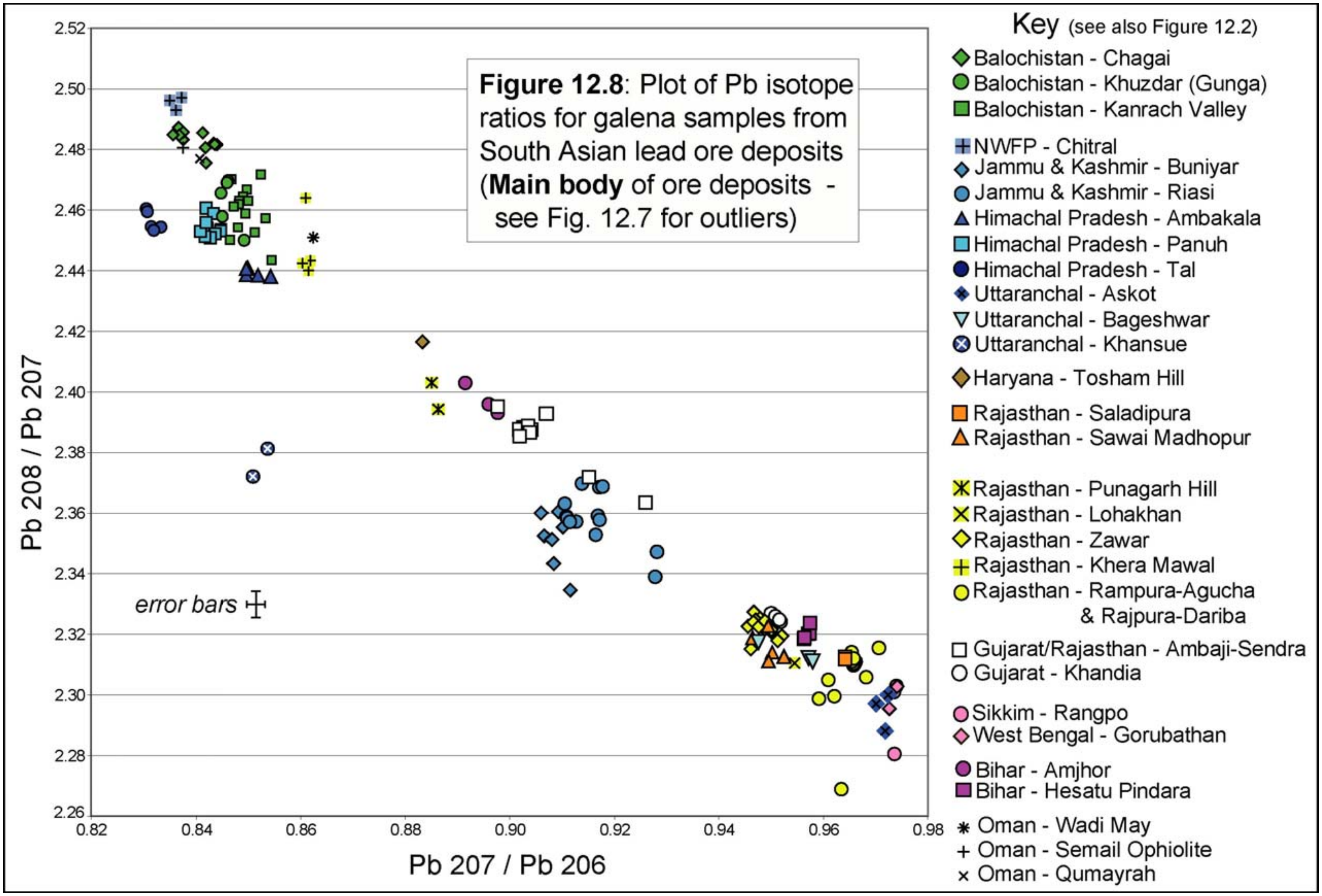
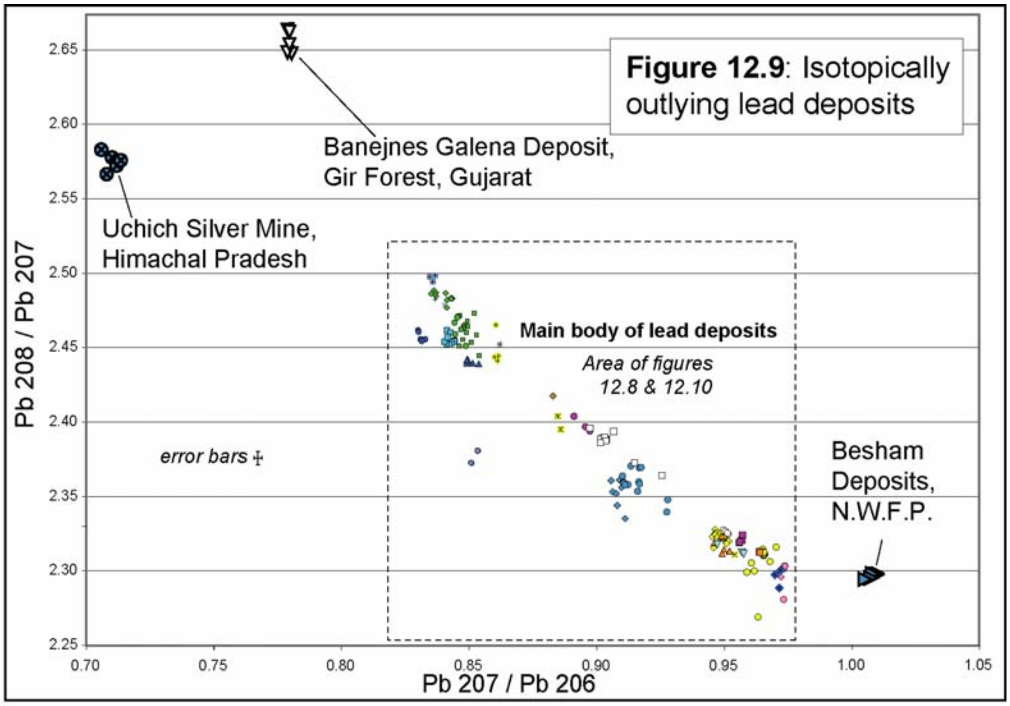
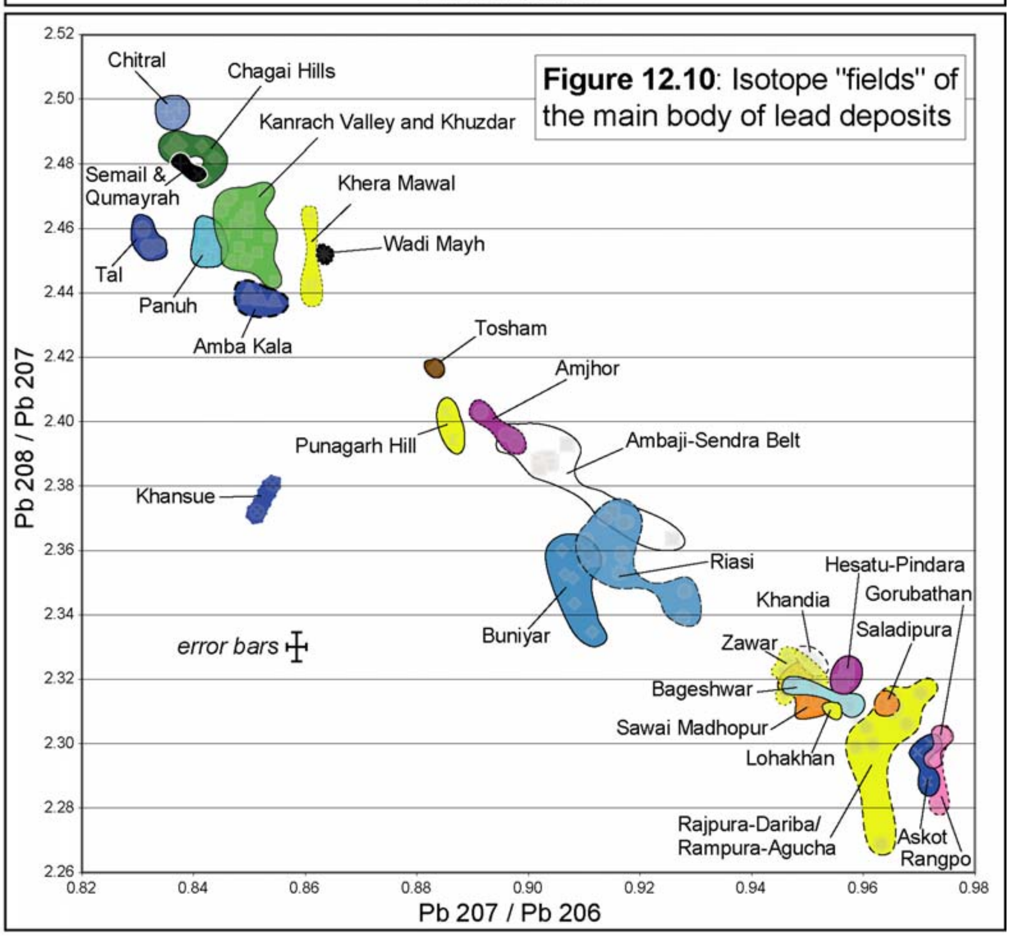


Figure 12.8: Plot of Pb isotope ratios for galena samples from South Asian lead ore deposits (**Main body** of ore deposits - see Fig. 12.7 for outliers)


Figure 12.9: Isotopically outlying lead deposits
Banejnes Galena Deposit, Gir Forest, Gujarat
Uchich Silver Mine, Himachal Pradesh
Main body of lead deposits
Area of figures 12.8 & 12.10
error bars
Besham Deposits, N.W.F.P.
Pb 208 / Pb 207
Pb 207 / Pb 206
2.65
2.60
2.55
2.50
2.45
2.40
2.35
2.30
2.25
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05


Figure 12.10: Isotope "fields" of the main body of lead deposits
Chitral
Chagai Hills
Kanrach Valley and Khuzdar
Semail & Qumayrah
Khera Mawal
Wadi Mayh
Tal
Panuh
Amba Kala
Tosham
Amjhor
Punagarh Hill
Ambaji-Sendra Belt
Khansue
Riasi
Hesatu-Pindara
Khandia
Gorubathan
Saladipura
Buniyar
Zawar
Bageshwar
Sawai Madhopur
Lohakhan
Rajpura-Dariba/ Rampura-Agucha
Askot
Rangpo
error bars
Pb 208 / Pb 207
Pb 207 / Pb 206
2.52
2.50
2.48
2.46
2.44
2.42
2.40
2.38
2.36
2.34
2.32
2.30
2.28
2.26
0.82
0.84
0.86
0.88
0.90
0.92
0.94
0.96
0.98

Gujarat into south central Rajasthan, falls toward the middle of the plot. A few remaining deposits in Rajasthan trend toward the upper left. All of the lead deposits in Balochistan, however, plot squarely in the far upper left of the figure. Although samples from sources in the Himalayas and the NWFP fall at several different places across the trend, they mostly plot apart (although there are degrees of overlap in places) from the other deposits. The complex geologic histories and processes that affect the isotopic composition lead occurrences in these regions and cause them to plot as they do is not the subject matter of this dissertation. What is important with regard to this study is that lead ores deriving from the various regions are, to a very large degree, isotopically distinct from one another. Therefore, when a question is posed such as – Did the metal for these lead or silver artifacts come from sources in Rajasthan, Balochistan, the Himalayas or elsewhere? – then providing an answer may very well be possible with reference to this Pb isotope database. I address these very questions in the upcoming sections of this chapter.

To aid in interpretations of the archaeological Pb isotope data, I have created a version of the bivariate plot (Figure 12.10) in which the different groups of lead ore occurrences (or "fields") that comprise the main body of geologic samples have been outlined and labeled. The shapes demarcating ore fields were drawn by hand and are *not* statistical confidence intervals. They are meant only to be visual guides (it is easier to see individual points plotted against solid shapes versus numerous data points). Individual data points are still visible as lightly superimposed geometric shapes. Crossed bars representing the overall range of analytical error (standard deviation of the mean of repeated measurements of the NIST lead isotope standard) are present on each plot.

Determining the probable geologic proveniences of lead artifacts from Harappa

Thirty-four "lead" artifacts, in total, have been recovered during HARP excavations and Pb isotope data have been produced for all of them using the EDTA/ICP-MS method. Nineteen are raw lead ores (Appendix 12.2) while the remaining ones are finished items, lead slags, melted lumps and residues (Appendix 12.3). Examples have been found on every mound and in the cemetery area (Figure 12.11). One ore fragment was found in Ravi Phase (Period 1) levels, two finished items were found in Period 3B burial contexts and a total of 10 artifacts (including ores, residues, slags and finished items) come from Period 3C levels. The remaining 22 lead artifacts are from surface or disturbed contexts.

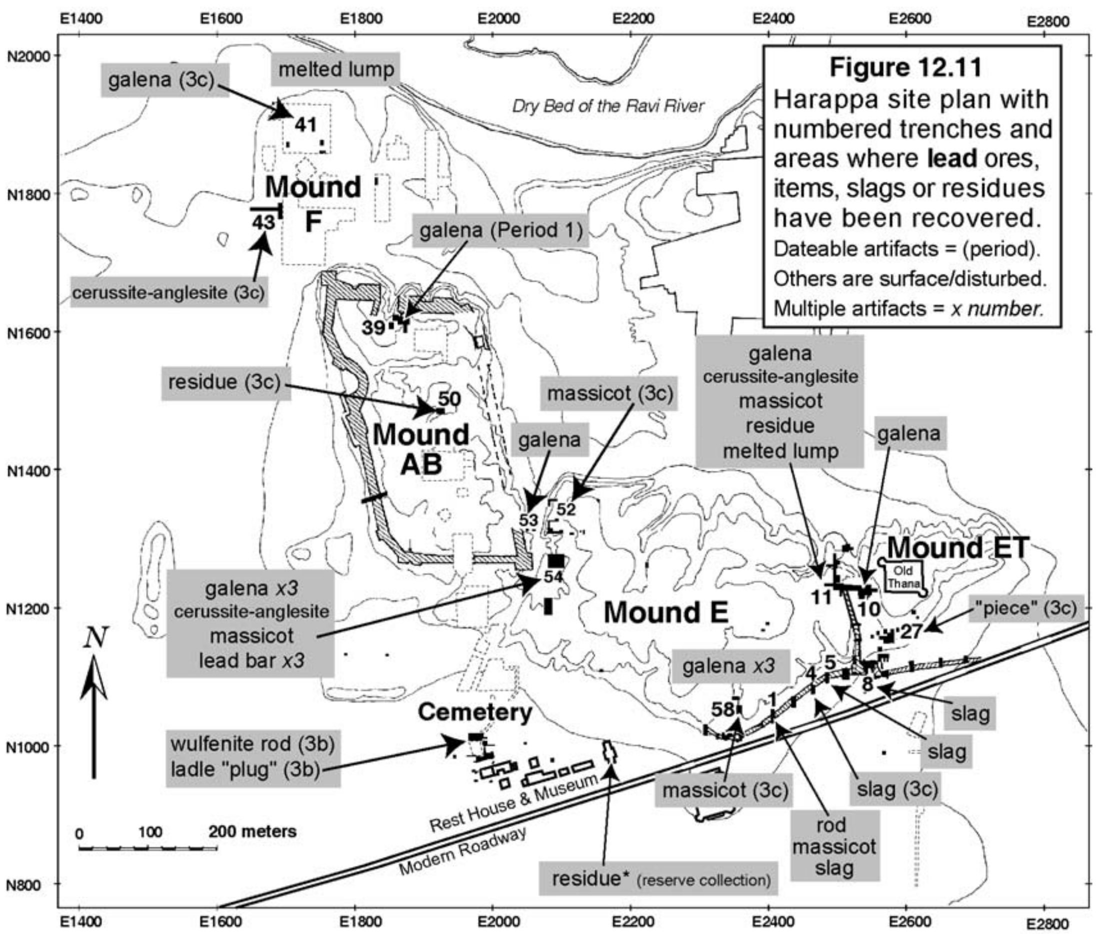


Figure 12.11
Harappa site plan with numbered trenches and areas where **lead** ores, items, slags or residues have been recovered.
Dateable artifacts = (period).
Others are surface/disturbed.
Multiple artifacts = *x number.*

Lead ores

When performing isotopic or elemental analysis of archaeological metals that have been altered in some way (smelted, forged, cast, alloyed, etc.) there is always the possibility that material from two or more geologic sources may be present in a single artifact. This can potentially lead to the misassignment of an artifact's provenience due to the obscuring of the chemical and/or isotopic characteristics used to match it to a geologic source. When the artifacts under examination are unadulterated metal ores, however, the potential mixing of sources is not an issue. For this reason, raw ore, when it is present at a site, is undoubtedly the best form of archaeological metal to study when attempting artifact-to-source correlation. Lead isotope analysis has been employed successfully in the past to help identify the probable sources of lead ore (galena) fragments excavated at sites in Egypt (Hassan and Hassan 1981) and North America (Farquhar and Fletcher 1984).

As discussed in Chapter 4, XRD analysis has shown that three distinct minerals (Figure 12.12) are represented among the 19 lead ore artifacts at Harappa: massicot (n=5), cerussite-anglesite (n=3) and galena (n=11). Besides being important ores for the metal lead (and, if argentiferous, silver), each are common mineral pigments/cosmetics and go by names like "plumbic ochre" (massicot), "lead white" (cerussite) and "surma" or "kohl" (galena). I discuss this aspect further in the section below where I examine lead residues found in small ceramic and faience bottles, which are possibly cosmetics. Lead minerals are also frequently employed in traditional medicines in South Asia (Murthy 1983) and the Arabian Gulf region (Worthing and Sutherland 1996). It is quite likely that when lead was intentionally brought to Harappa in raw form, it was for one of these uses.

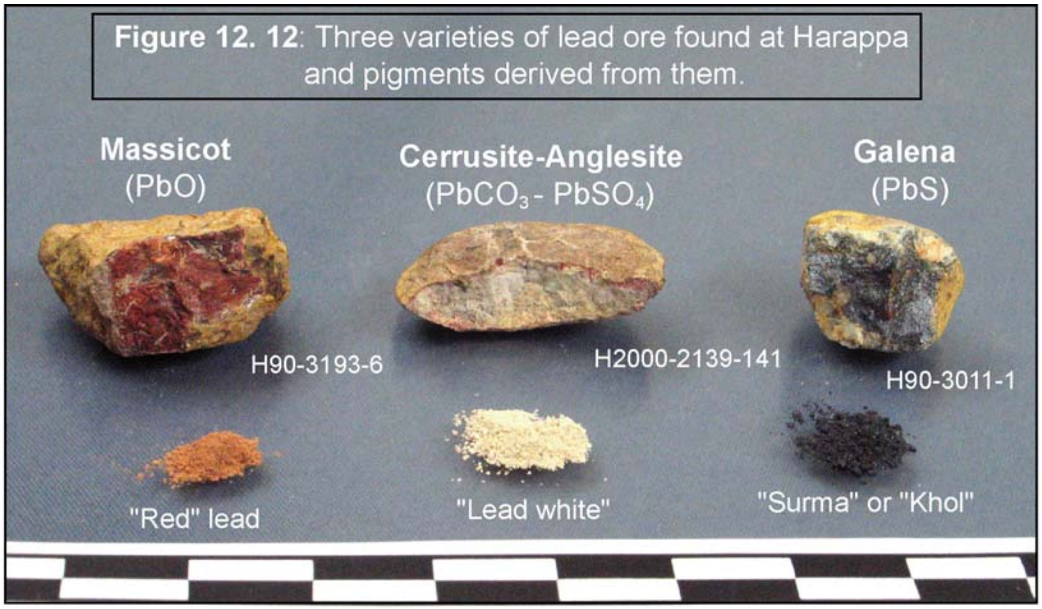


Figure 12. 12: Three varieties of lead ore found at Harappa and pigments derived from them.

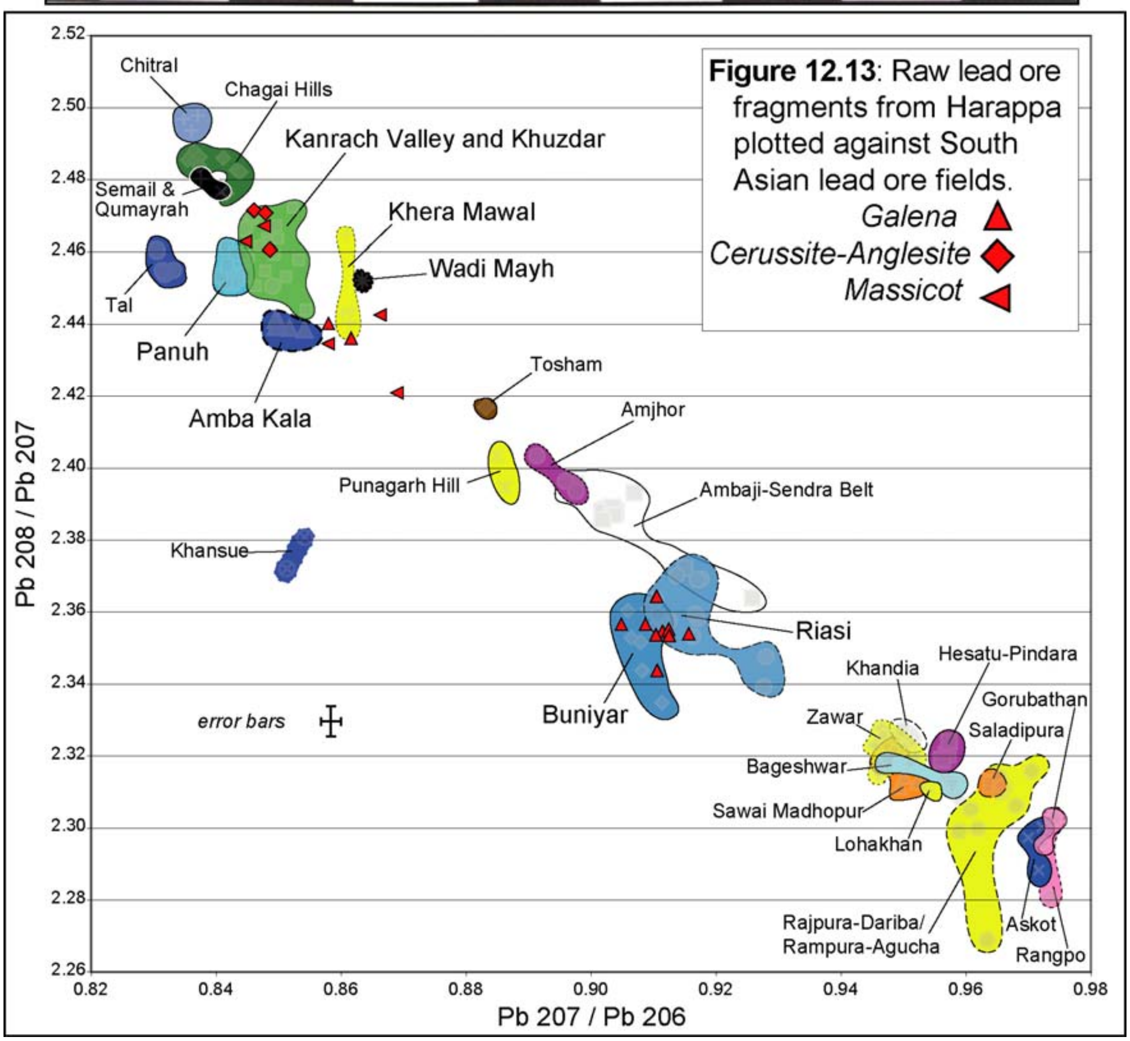


Figure 12.13: Raw lead ore fragments from Harappa plotted against South Asian lead ore fields.

When Pb isotope data for the 19 lead ore fragments from Harappa (Appendix 12.2) are placed on the bivariate of the main body of geologic samples (Figure 12.13), they more or less cluster in three areas. Nine artifacts fall within the fields of the Jammu and Kashmir deposits. Although a few of those are isotopically more analogous to either the Riasi samples or the Buniyar samples, most cluster in or near the area where the two sources overlap. Five of the ores plot with samples from deposits in Kanrach Valley and Khuzdar areas of southern Balochistan – sources that have largely indistinguishable Pb isotope characteristics. Here is an instance where having precise ^{204}Pb measurements might help to resolve these two sources. On the other hand, it might not. Although the two areas of lead mineralization lie around 180 km apart, both belong to a zone in Jurassic sediments along the western margin of the Indian Plate known as the "Las Bela-Khuzdar metallogenic province" (Jankovic 1986: 1). For now, the two sources have been grouped into one "field" that represents the region of southern Balochistan. The source association of the remaining five ore fragments is more ambiguous. Four of them fall around two deposits that are isotopically under-characterized – Amba Kala in Himachal Pradesh and Khera Mawal in southern Rajasthan. The final fragment has an isotopic composition that is unlike any of the deposits included in the lead database and plots somewhat away from the others.

Interestingly, the nine ores that appear to be from the Jammu and Kashmir sources are all galena fragments. The other two galena artifacts are among the samples ambiguously grouped near the Amba Kala and Khera Mawal deposits. I can relate that those particular artifacts (H90/3011-148 & 149) *look* much more like they came from the

latter deposit (Amba Kala galena is coarsely mineralized while that from Khera Mawal is very fine-grained like the artifacts) but that, admittedly, is a superficial observation.

The only three examples of cerussite-anglesite from Harappa all plot closely together with the samples from southern Balochistan sources. It is not presently possible to isotopically differentiate lead occurrences in the Khuzdar area from those in the Kanrach Valley and the mineral could have come from deposits in either area. It has been reported to occur in "small quantities" in the Las Bela district (Gazetteer of Las Bela 1907: 119) and is found in the oxidation zone of the deposit at Gunga (Jankovic 1986: 4) in the Khuzdar district. The "chief ore" at Shekran is cerussite (Heron and Crookshank 1954: 93) and fragments the mineral have been recovered during both previous (Hargreaves 1929: 33) and current (Ute Franke-Vogt *personal communication* 2005) excavations at the prehistoric site of Sohr Damb/Nal, which is around 15 to 25 km west of the Khuzdar deposits.

Two of the fragments of massicot – a mineral that likewise forms in the oxidation zones of lead deposits, also appear to come from southern Balochistan sources. The three other examples of that mineral plot with two galena fragments in the "ambiguous" region.

"Finished" lead artifacts

Six "finished" lead artifacts have been recovered at Harappa (Figure 12.14). These include a rivet or plug used to repair a shell ladle (Dales and Kenoyer 1989a: Fig. 58), several small rectangular "bars" one of which (H2000/2174-321) appears to be inscribed, a corroded tubular "rod" fragment and a tiny squarish lead "piece." All of them appear to be composed of entirely of lead metal. As this study now shifts from raw ores to artifacts that have been manipulated in various ways, it is worth emphasizing again that such artifacts,

Figure 12.14: "Finished" lead artifacts from Harappa



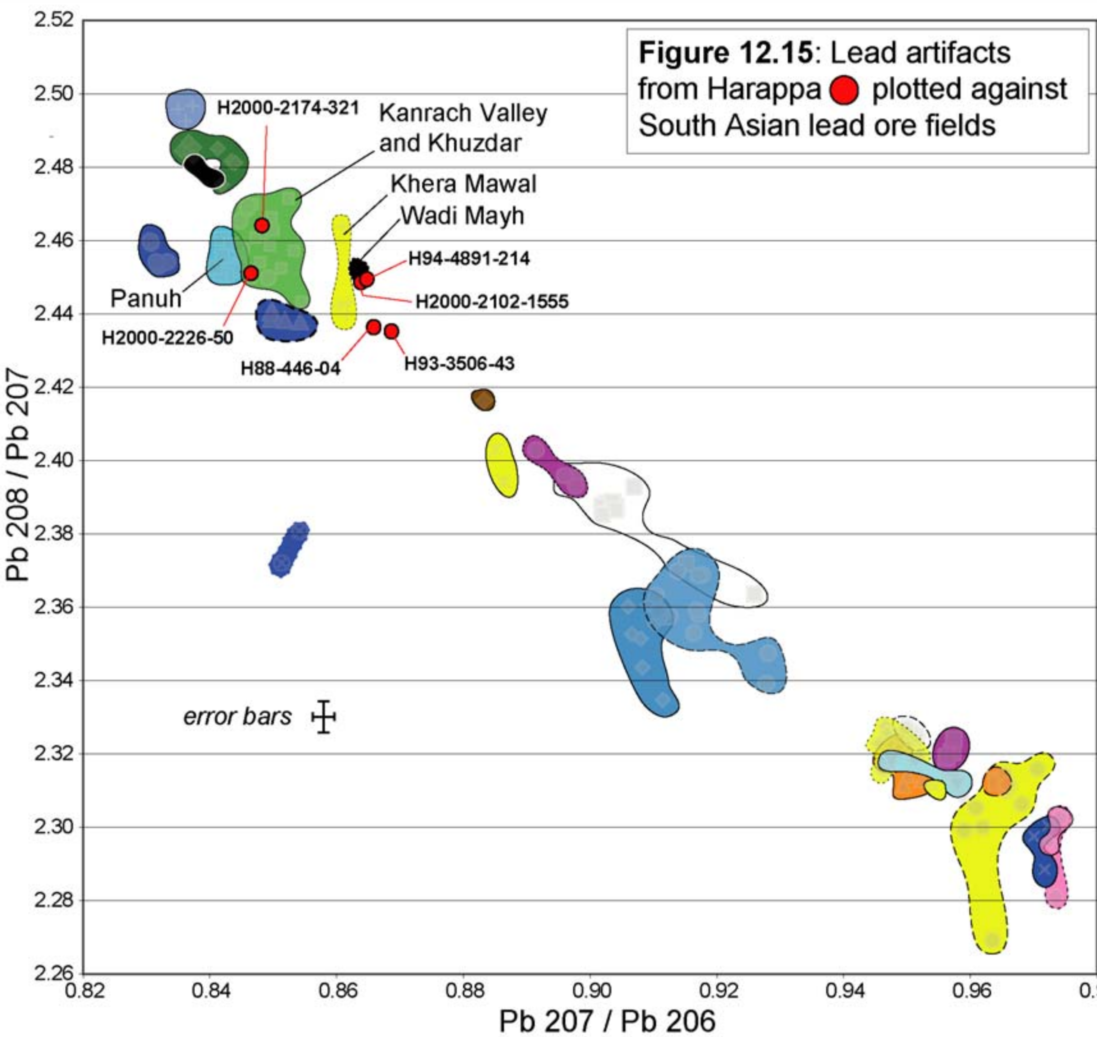


Figure 12.15: Lead artifacts from Harappa (red dot) plotted against South Asian lead ore fields

be they "finished" items, slags or residues, might potentially possess Pb isotope characteristics that reflect the mixing of lead from multiple geologic sources. When an artifact is composed of metal from only two sources, its measured isotopic values will plot somewhere along a *mixing line* between them (Klein et al. 2004: 470). If the end members of a mixing line are well known and no other deposits are believed to exist that have isotopic values intermediate to them, then a case can be made that artifacts plotting along that line contain metal from both sources (ibid.). However, if other geologic deposits exist between the end members of a potential mixing line, then those same artifacts could be misassigned to them or, alternately, if an intermediate deposit is unknown then an artifact derived from it could be misinterpreted as being composed of a mix of materials from the two end member sources. The situation is further complicated when materials from more than two deposits are used to fashion an artifact or when lead derived from different types of metals are mixed (for instance if copper containing trace lead is alloyed to silver extracted from a lead deposit). In short, when examining any type of artifact other than a raw ore, the possibility *always* exists that measured isotopic values may be a reflection of something other than the actual isotopic characteristics of single geologic source. This is a fact that must be kept in mind when interpreting data of this kind, most especially assays of "finished" artifacts.

When the Pb isotope determinations (Appendix 12.3) for the six "finished" artifacts are placed on the bivariate plot (Figure 12.15), they are distributed among some of the same areas where the lead ores previously clustered. The lead composing two of the bars (including the inscribed one) appears to have been derived from sources in southern

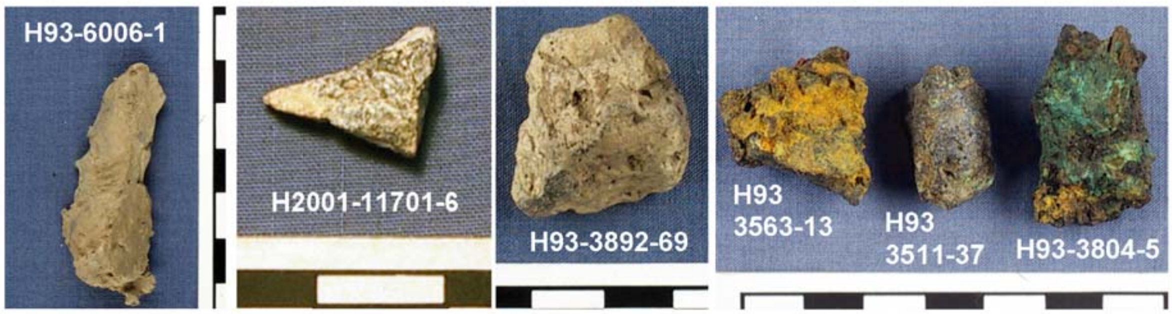
Balochistan (although one bar plots at the point where the isotopic values of that source region begin to overlap with values for samples from the Panuh deposit of Himachal Pradesh). The lead used to make the ladle plug and the rod falls into the same general "ambiguous" area that several of the lead ores previously fell. These two artifacts, however, plot somewhat farther way from the Khera Mawal deposit samples. Also plotting in this same general area but directly adjacent to the single data point for galena from the Wadi Mayh area of Oman is the remaining bar and the small lead "piece." These, if real, are interesting and important source associations. However, caution in the interpretation of these data is advised as 1) the Wadi Mayh source is represented by only *one* sample, 2) the Khera Mawal source of southern Rajasthan is within the range of analytical error and 3) the isotopic characteristics of these artifacts *could* be the result of source mixing.

Lead slags and lumps

Isotopic assays were made of six metallurgical craft indicators (Figure 12.16) from Harappa composed of or containing significant amounts of lead. Heather Miller conducted (1994a, 1994b, 1999) a series of surface and subsurface surveys of the site in an effort to locate areas where different types of craft activities were conducted. It was on the southern slope of Mound E that she encountered the heaviest concentration of metallurgical craft indicators (metal or metalliferous scraps, slags, prills, crucible and kiln fragments) (Miller 1999: 414-419). Most of these were related to copper production but a few of the slags quite clearly had a significant lead component (i.e. yellow oxidized patches and/or visible lead prills). A yellow patch on one slag sample (H93/3804-5) that Miller had analyzed using XRD and XRF (X-ray fluorescence) was shown contain, among other things, lead

bromide and massicot (Heather Miller *personal communication* 2003). A few non-descript melted lumps of lead have also been recovered during surveys and excavations at Harappa.

Figure 12.16: Lead slags and melted lead lumps from Harappa



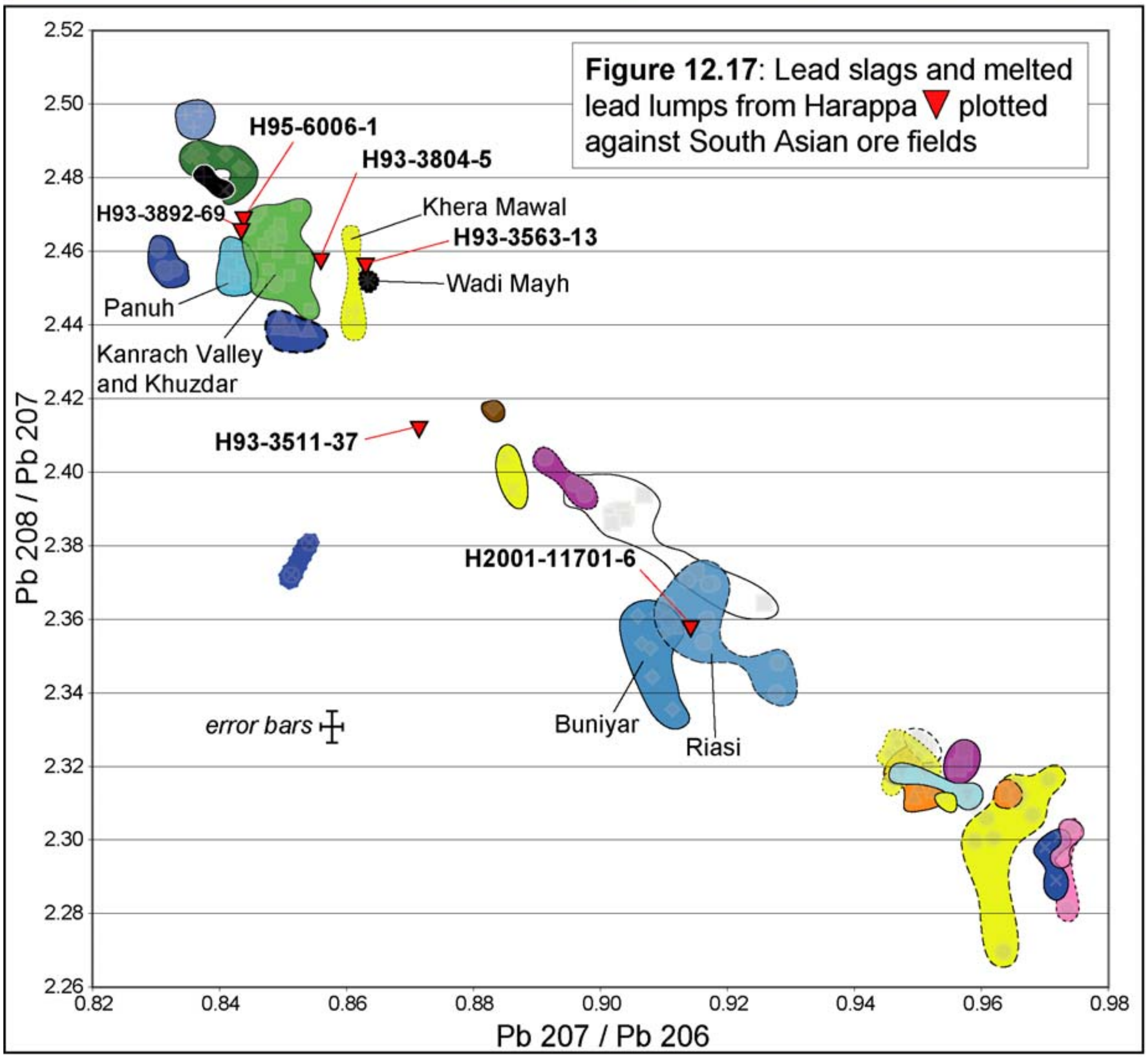


Figure 12.17: Lead slags and melted lead lumps from Harappa ▼ plotted against South Asian ore fields

When the Pb isotope determinations (Appendix 12.3) for the lead-rich metallurgical slags and melted lead lumps are placed on the bivariate plot (Figure 12.17), they again cluster in the same three general areas as the ores and finished artifacts did. One of the lumps (H93/6006-1) and a frothy slag with lead prills (H93/3892-69) fall closely together on the upper left margin of the southern Balochistan cluster, while another slag (H93/3804-5) plots on the right margin of that cluster. A third slag (H93/3563-23) falls directly adjacent to the Wadi Mayh and Khera Mawal source samples and a fourth (H93/3511-37) lie in the "ambiguous area," away any of the sources in the database. The other lead lump (H2001/11701-6) is isotopically analogous to deposits in the Jammu and Kashmir region.

The possibility (even the probability) that these artifacts contain lead from multiple geologic sources should be kept closely in mind when interpreting this data. Copper oxidation (identified by XRD as *atacamite* [$Cu_2Cl(OH)_3$] – Heather Miller *personal communication* 2003) is, in addition to the previously mentioned patch of lead oxidation, quite clearly evident on slag H93/3804-5 (Figure 12.16 far right). Although most of the lead measured on this sample would have been extracted from the lead-rich portion of the artifact, it is still unknown whether or not that was representative of more than one geologic source or how any trace amounts of lead in the copper-rich portion may have affected the results. Some of these artifacts, therefore, may fall upon a yet to be defined mixing line. For instance, a mixture of lead from a source in southern Balochistan with that from one in the Jammu and Kashmir region would probably have isotopic values much like those exhibited by slag H93/3511-37. The possibility that this occurred is evaluated again later in this chapter when isotopic data for all lead artifacts are examined together.

Lead residues

In this section, I examine the compositions and probable geologic proveniences of lead residues found in small bottles and/or in other forms at Harappa (Figure 12.18). Lead minerals were used in many parts of the ancient world to produce pigments for both painting and self-adornment (Nriagu 1983; Rapp 2002: 210-211) and these residues are very likely the remains of substances that Harappans used as cosmetics. "Surma" (or "kohl") is a silvery-black eye salve/cosmetic that is ostensibly made using antimony. In reality it usually contains the lead mineral galena (al-Hazzaa and Krahn 1995; Hardy et al. 1998; Parry and Eaton 1991; Vaishnav 2001). Surma/kohl, other lead-based cosmetics (such as "lead white" made from powdered cerussite) and the vessels designed to hold them ("kohl" pots, jars or tubes made of a wide range of materials) are very well known from ancient Egypt and the Near East (Lucas and Harris 1999; Ungár et al. 2002; Walter et al. 1999). Although it is commonly assumed that the many miniature ceramic, faience, stone or metal vessels found at Harappa and Mohenjo-daro held, among others things, similar kinds of cosmetics, documentation of these substances has been limited. A small alabaster pot at Mohenjo-daro was found to contain galena (Mackay 1938: 665) and a white substance in a small beaker at Harappa was identified as cerussite (Vats 1940: 312).

In January of 2004, I had the opportunity to examine small vessels from past excavations at Harappa that were stored reserve collection of the Harappa Museum. Most contained no visible evidence of any residue that may have provided clues as to what they once held. However, the rims or interiors of six ceramic bottles (Figure 12.18 bottom left) were darkened as if they had contained a black substance such as surma. Each bottle was

Figure 12.18: Three small cosmetic or "surma" bottles and a "rod" from Harappa.



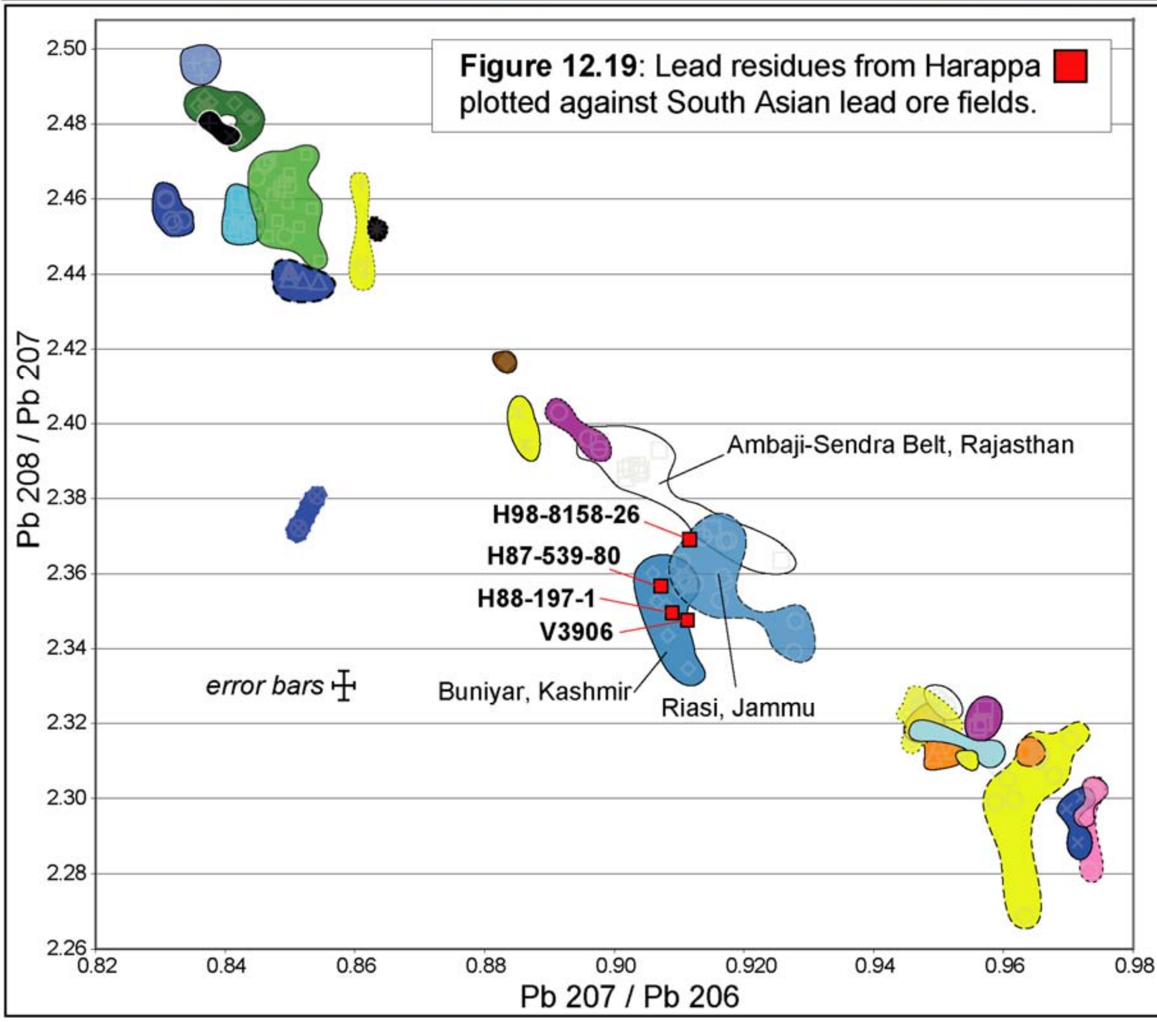
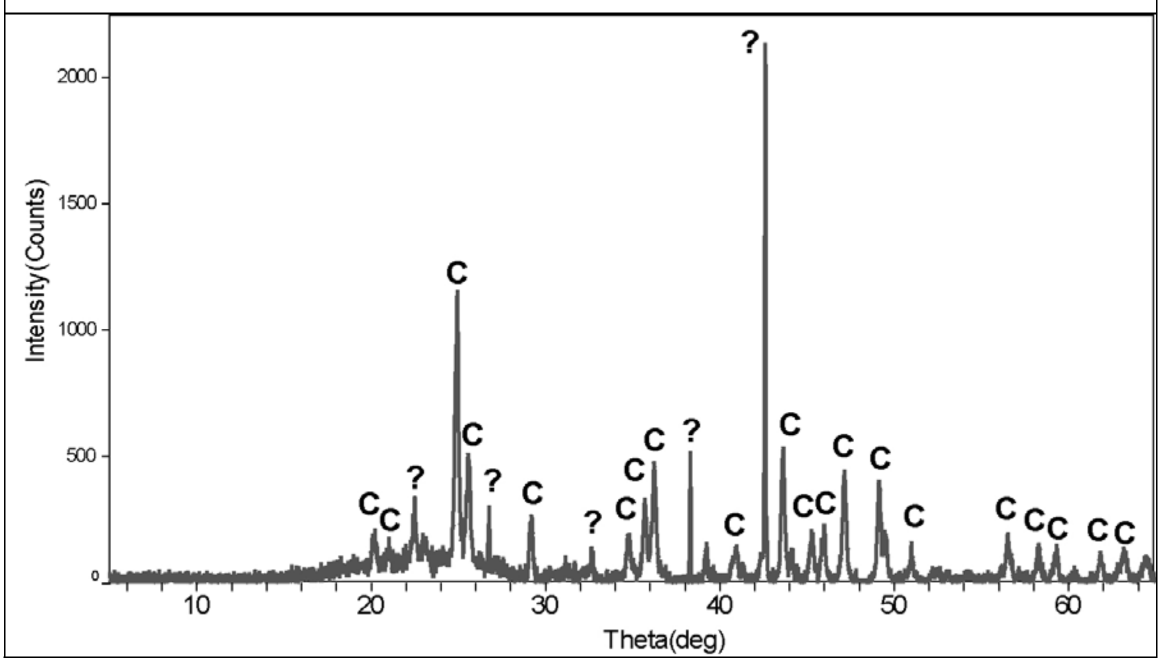


Figure 12.19: Lead residues from Harappa ■ plotted against South Asian lead ore fields.

sampled using the EDTA technique to see if enough (or if any) lead was present on it for isotopic analysis. After the solutions were returned to Madison and assayed, it was determined that only one had contained any lead at all – a small jar from Vats' excavations (1940) identified by the number *3906* (Figure 12.18 top left). If the other vessels had once held a black cosmetic, it was probably made from perishable organic substances such as "lamp black mixed with fat" as Ernest Mackay had once proposed (1938: 665), rather than a lead mineral.

I also examined small bottles recovered during HARP excavations, two of which (Figure 12.18 – second and third image) were sampled for lead using EDTA. One of those (H87/539-80) still had a thick yellow and white residue on its interior. XRD analysis of that residue (Figure 12.20) indicated that it was composed of cerussite and another phase that, although I have not been able to positively identify it yet, has a major peak that is

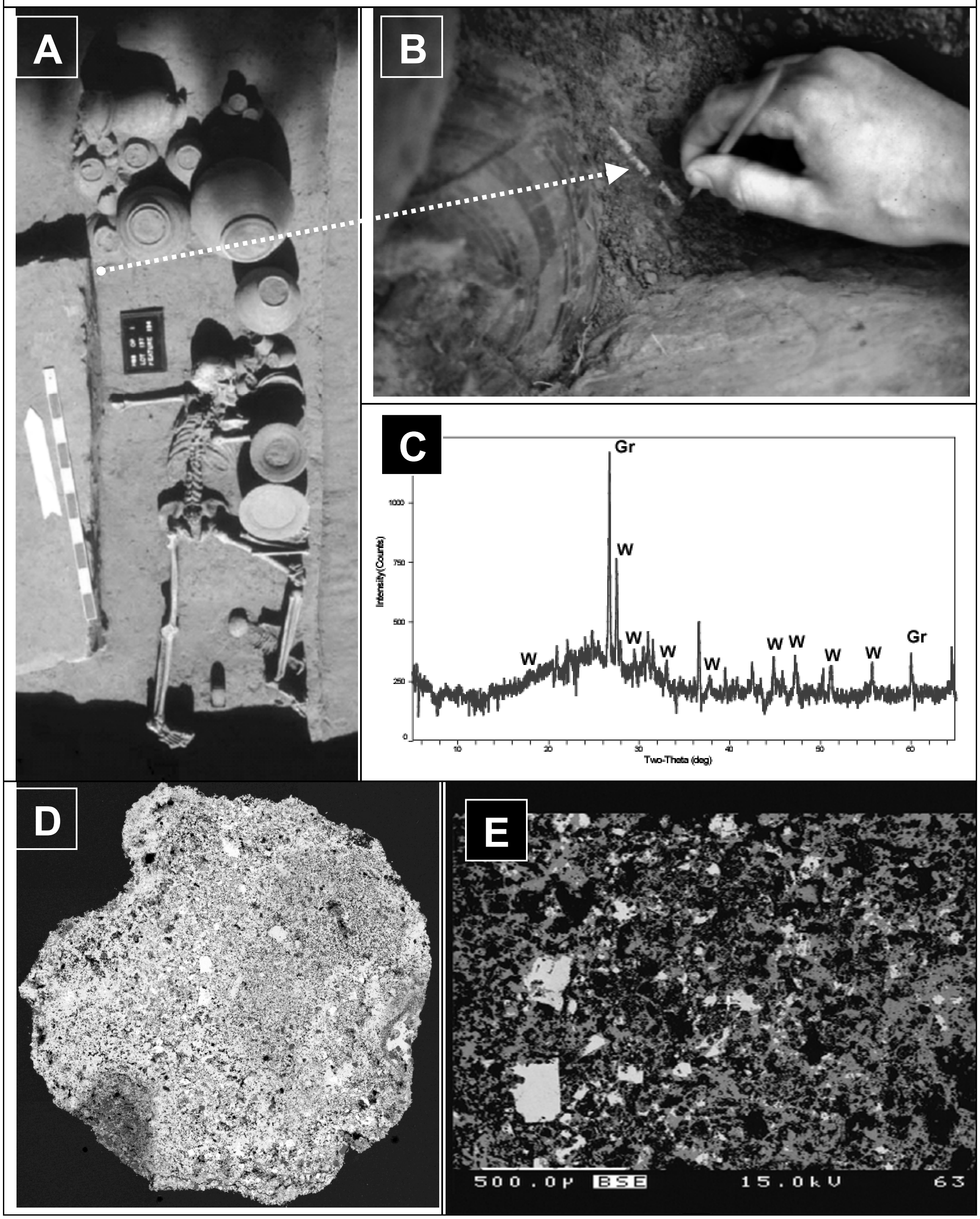
Figure 12.20: XRD of residue on the interior of a small vessel fragment [H87/539-80], Mound AB, Trench 50, Period 3C. **C** = cerussite peaks. **?** = unknown mineral(s)



reminiscent of a copper mineral of some kind. Although this residue is likely the remains of a cerussite-based cosmetic like “lead white”, it is not impossible that the bottle may have originally held a galena-based surma that has since oxidized as cerussite – a phenomenon documented in a study of kohl from Roman-era Palestine (Grüner 2002: 80).

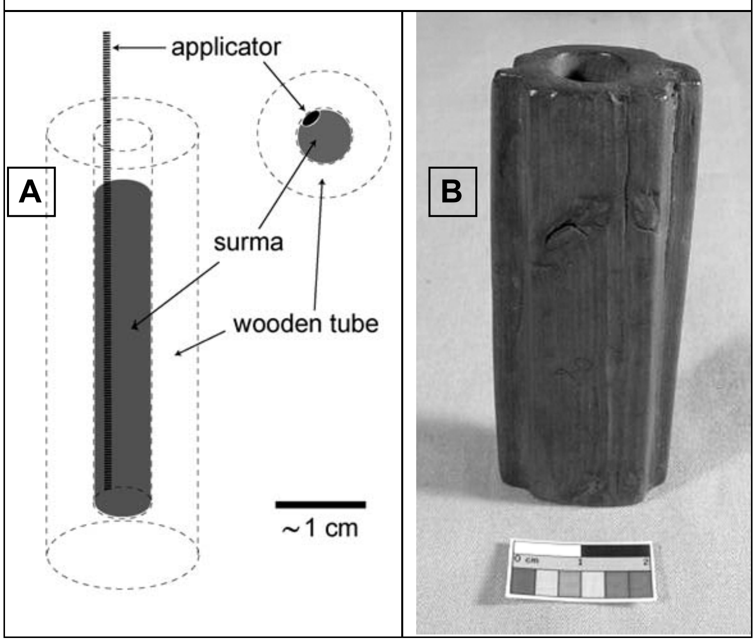
One particularly interesting residue from the HARP excavations, originally thought to be a metal “rod” (Figure 12.18 – artifact H88/197-1), was recovered in the grave of an adult woman in a disturbed (in antiquity) cemetery area burial dating to Period 3B (Figure 12.21 A). The “rod”, which is somewhat fragile and not as heavy as would normally be expected of an item made of metal, was found in fragmentary condition (Figure 12.21 B). The material that it is composed of was initially classified by Dales and Kenoyer (1989: 91) as “lead/orpiment” because of its bright orange-yellow (very orpiment-like) oxidized exterior. When I first examined this artifact in December of 2003, a small amount of powder had accumulated in the bag holding it, which I collected and analyzed using XRD. The resulting pattern (Figure 12.21 C) indicated that the “rod” (or at least the powder coming off of it) was composed primarily of *wulfenite* (peaks identified with a W on the XRD scan) and *graphite* (identified with a Gr). Wulfenite – lead molybdate ($PbMoO_4$), is another mineral found in the oxidation zones of lead deposits and sometimes has an orange-yellow appearance (Read 1979: 466). Graphite is, of course, pure native carbon. It crossed my mind that the carbon in the artifact, although identified as graphite, may actually be charcoal, “bone black”, or “lamp black” – carbonaceous substances used as black cosmetic pigments in South Asia (O.P. Agrawal 1999: 193-194). However, carbons such as these are amorphous and would not have registered peaks on the XRD scan.

Figure 12.21: Excavation and analysis of a lead artifact. [A] A small rod was found in two pieces within Feature 194a – a Period 3B burial. [B] Excavation of the artifact, H88/197-1 [C] XRD revealed the rod was composed of *wulfenite* (lead molybdate) and *graphite*. [D] BSE image of rod section [E] detail of rod matrix with *galena* crystals.



A small portion of one of the broken ends of the "rod" was removed for further study using EMPA. The BSE image of this piece in section (Figure 12.21 D) revealed that it is not composed of solid metal (hence the artifact's light weight) but rather is a composite of several granular substances of varying consistencies that have been mixed together. EDS scans indicated that one of these substances was lead sulphide (galena). Cubic crystals of galena can be clearly seen in the artifact's matrix (Figure 12.21 E).

Figure 12.22: [A] Approximated shape of a wooden "surma tube" and the position of a cosmetic applicator set into it. [B] Wooden "kohl tube" from Gurob, Egypt, *Petrie Museum of Egyptian Archaeology, University College London*



I believe that this artifact, rather than being the remnants of a rather fragile "rod", may instead be the solidified residue of surma powder that was once held in the tube-shaped interior of a container (Figure 12.22 A) made of a perishable material like shisham wood or bamboo. Cylindrical "kohl tubes" made of wood or reed are well known from ancient Egypt. The one shown above (Figure 12.22 B) was excavated by Flinders Petrie at New Kingdom site of Gurob (Thomas 1981: 63 [UC 7891]). There is a groove running down the lengths of the Harappan "rod"/residue fragments (visible in section on the upper left of Figure 12.21 D) that may be the place where a thin cosmetic applicator (probably also perishable) was set into the powder. Over

time, the perishable tube and applicator disintegrated leaving only the lead-based powder, which consolidated as it oxidized, in the shape of the container's interior.

The results of the Pb isotope assays (Appendix 12.3) indicate (Figure 12.19) that the lead in all four of the cosmetic residues from Harappa was probably acquired from sources in the Jammu and Kashmir region. It should be noted, however, that although the "rod"/residue (H88/197-1) that contained wulfenite would seem to have come from one of the Buniyar sources, this mineral has not as yet been reported in that area or, for that matter, anywhere in Jammu or Kashmir. Even so, wulfenite can form due to lead-molybdenum impurities in *sphalerite* (Guilbert and Parks 1986: 809) – a zinc mineral which is found throughout the zone of sulphide mineralization at Buniyar (Sharma and Sachan 1998). Moreover, mineralization there is thought to perhaps be epigenetically related to intrusive granitoid plutons in the vicinity (Kaul 1981), which could have easily contributed the molybdenum impurities that oxidized with lead as wulfenite ($PbMoO_4$). Also significant with regard to the "rod"/residue, is the fact that graphite associated with igneous rocks is abundant in the vicinity of Buniyar (Mehta 1957) as well as nearby the unassayed lead deposits of the Doda district (Gupta and Guha 1988).

Although more geologic research remains to be done in order to fully understand the nature of lead deposits in Jammu and Kashmir, it is of interest to note here that the southernmost occurrences in the Buniyar area (those nearest to the igneous intrusives) are found around the village of "Surmawali" (Raina 1977), which is presumably so named (as many villages in the vicinity of lead deposits seem to be, e.g. *Surmai* village in the Khuzdar district of Balochistan) because the raw material for surma is obtained at this location.

Isotopic assays of lead and silver artifacts from seven other prehistoric sites

In this section, I present the results of a series of Pb isotope analyses made on various kinds of lead artifacts from the prehistoric sites of Shahr-i-Sokhta, Mundigak, Mehrgarh, Nausharo and Mohenjo-daro (Appendix 12.4). Isotopic assays of silver artifacts from Mundigak, Nagwada, Mohenjo-daro and Allahdino (Appendix 12.5) have been made and are also evaluated in relation to the lead deposits database. Although these seven ancient settlements are not the central focus of this dissertation, incorporating data on artifacts from them into this study 1) allows the lead acquisition networks that residents of Harappa were involved in to be viewed from a perspective that is more holistic, 2) provides an indication (by proxy) of what the isotopic character of lead deposits in certain regions (southern Afghanistan and eastern Iran) not represented in the database *may* be like and 3) permits a material type (silver) to be examined that was widely used by Indus Civilization peoples, but for which examples from Harappa are not available for analysis.

The sites and artifacts

Lead artifacts from five prehistoric sites were sampled and analyzed using the EDTA/ICP-MS technique. Data for and descriptions of individual artifacts can be found in Appendix 12.4. All site locations are noted on Figures 12.2 and 12.3.

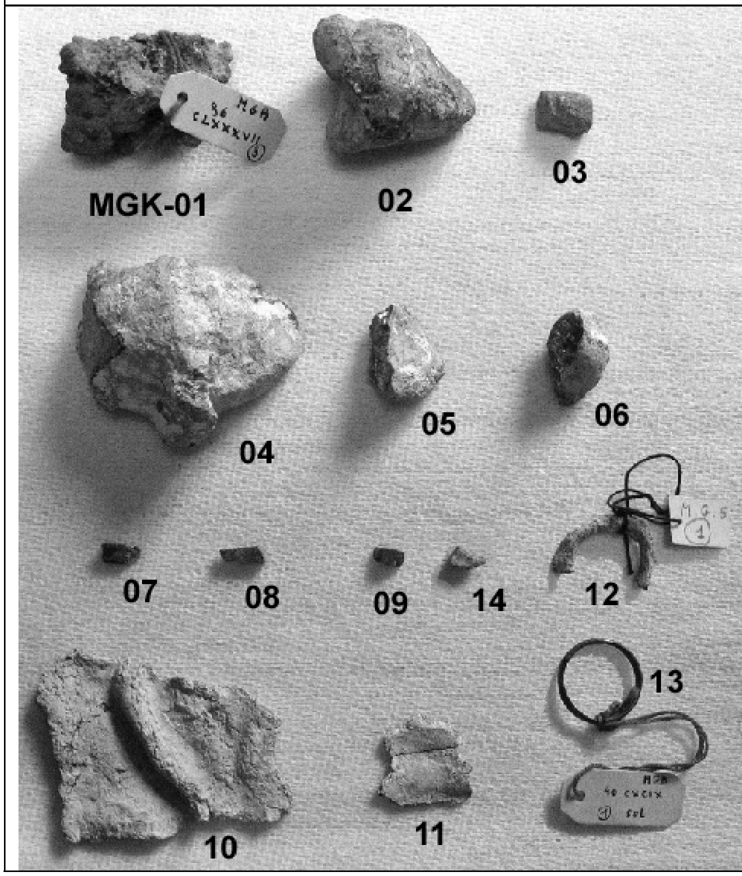
Dr. Massimo Vidale graciously provided access to two galena samples from the Helmand Civilization urban center of Shahr-i-Sokhta in the Seistan Basin of eastern Iran (Tosi 1982). As the majority of metallurgical finds from this site date to the mid-third millennium BC (ca. 2700 to 2500 BC) levels there (M. Tosi cited in Hauptmann 2003: 198), it can probably be assumed that these archaeological ores, which are part of a larger

collection of mostly copper artifacts and manufacturing debris presently under examination from that site (Giardino et al. *in preparation*), were deposited at a time roughly ranging from late Period 2 to early Period 3A at Harappa. Although few in number, these artifacts can provide a general idea of what the isotopic character of lead deposits in eastern Iran *may* be like, assuming, of course, they were obtained from that region.

Galena along with sheet-like lead fragments and a ring made of that metal (Figure 12.23 A – MGK 1 to 12, & 14) were recovered in Period III and IV levels (ca. Harappa Period 2 to mid-Period 3) at the Helmand Civilization settlement of Mundigak (Casal 1961) in southern Afghanistan. These artifacts are now in the collections of the Centre de Recherches Archéologiques Indus-Balochistan, Asie Centrale et Orientale at the Musée Guimet, Paris, which is presently headed by Dr. Jean-François Jarrige. I was kindly allowed to extract lead from these artifacts, which, as discussed, is very likely to have come from a source around eight kilometers away from Mundigak itself (Jarrige and Tosi 1981).

Also in the collections at Musée Guimet are a number of lead artifacts from the ancient settlements of Mehrgarh and nearby Nausharo, which are located at the foot of one of the major passes connecting the Indus Valley to the central Balochistan highlands and beyond to the Helmand Basin. Dr. Jean-François Jarrige, who directed excavations at both sites, generously permitted lead to be extracted from these artifacts (not pictured) for analysis. The Mehrgarh artifacts are galena fragments from the site's Balochistan Tradition Neolithic levels (Period IIB – ca. 5000 BC). The artifact from Nausharo is a lead ring from the initial Indus Civilization levels (roughly equivalent to Period 3A at Harappa) at that site. The nearest lead sources are in the Khuzdar region, around 200 km to the southwest.

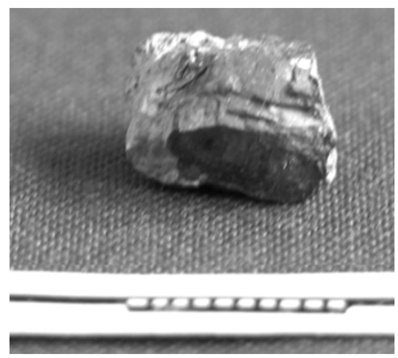
Figure 12.23: Lead and silver artifacts from Mundigak and Mohenjo-daro



A. Lead and silver artifacts from Mundigak (MGK)

- Galena fragments (MGK-01 to 09, & 14)
- Lead sheet (10 & 11)
- Lead ring fragment (12)
- Silver ring (13)

B. Galena fragment from Mohenjo-daro (MD-L1)



Two lead samples from the Indus Civilization city of Mohenjo-daro in northern Sindh were assayed. The first is a galena fragment (Figure 12.23 B) recovered during the surface surveys by the German-Italian mission to that site (Jansen and Urban 1984), which is now stored at the Department of Archaeology and Museums' Excavation Branch collection in Karachi. The other sample was extracted from a "surma" residue in small ceramic vessel on display in the cases of the Mohenjo-daro site museum. Although it is presumably from one of the early excavations at that site, no accession numbers or other identifying information could be found for it. The closest lead deposits to that site are those in the Khuzdar region – around 170 km to the west-northwest.

The Pb isotope characteristics of silver artifacts from four sites were determined using ICP-MS. Most were sampled using the EDTA lead extraction technique. Immersion time in the sampling solution was tripled to six minutes because, presumably, only a trace amount of lead was present in the metal. Although lead was indeed extracted from silver items in amounts considerably lower than for those composed of lead, concentrations were still sufficient for isotopic analysis. Lead from one artifact (from Nagwada), which was in Madison undergoing other types of analysis, was brought into solution by dissolving precisely 0.02 grams of metal from it in ultra-pure nitric acid. Isotopic data for and descriptions of the silver artifacts discussed below can be found in Appendix 12.5.

A small silver ring (Figure 12.23 A – MGK 13) from Mundigak Period IV was sampled for Pb isotopes at the same time as the lead artifacts from that site discussed above.

A detailed analysis of a silver ring fragment (Figure 12.24 A) from the site of Nagwada (Hegde et al 1988) in the Rupen estuary of northern Gujarat was begun in collaboration with one of the excavators of that ancient settlement, Dr. Kuldeep Bhan of the Department of Archaeology at Maharaja Sayajirao University, Gujarat. The artifact is heavily corroded. BSE imaging (Figure 12.24 C) and EDS scans revealed that the silver (Ag) metal of the ring's exterior has undergone alteration to silver bromide (AgBr), encompassing some sand grains (SiO_2) from the sediment it was buried in as it did so. The interior of the artifact (Figure 12.24 D), however, is unaltered. Five WDS scans (Figure 12.24 B) were conducted across the center of this unaffected portion and then averaged in order to quantify the absolute amounts of silver, copper (Cu), lead and gold (Au) in the metal. The silver ring was found to be very pure (≈ 98.5 %); even more so than those silver

Figure 12.24: EMPA analysis of a silver ring fragment from Nagwada

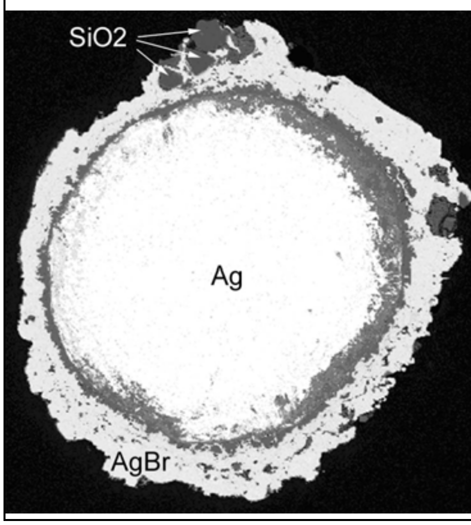
A. Silver ring fragment



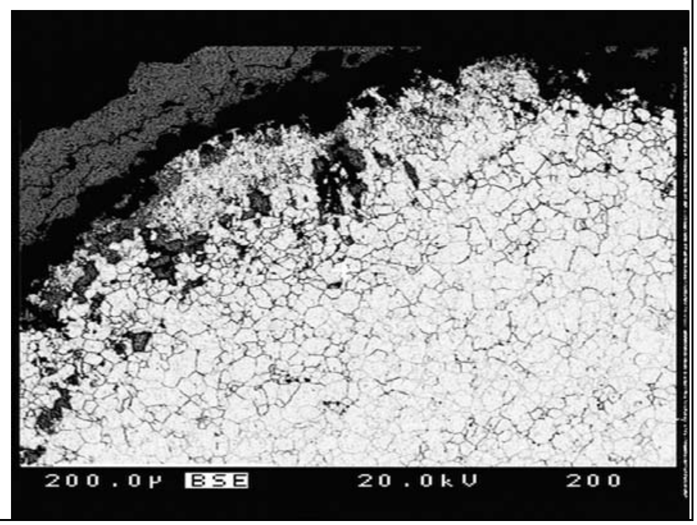
B. WDS scans of five points on the ring's interior

	1	2	3	4	5	*average*
Ag %	97.90	98.71	98.26	98.86	98.60	***98.47***
Cu %	1.71	1.49	1.34	1.76	1.53	***1.57***
Pb %	0.31	0.42	0.00	0.19	0.00	***0.18***
Au %	0.07	0.10	0.18	0.09	0.05	***0.10***
Total %	*99.99*	*100.72*	*99.78*	*100.90*	*100.18*	*100.32*

C. BSE image of ring section



D. BSE image of ring section (detail)



artifacts from Mohenjo-daro and Lothal that have been analyzed (summarized in Kenoyer and Miller Table 5.3). Copper (≈ 1.5 %) makes up most of the ring's non-silver content. Although it is likely that copper was deliberately alloyed with the silver during production of the ring, it is not impossible that it was retained from the extraction of silver from copper or lead ores. Although very little lead was present in the metal (≈ 0.2 %), enough could be brought into solution (as described above) for isotopic analysis using the ICP-MS.

This tiny ring fragment is of special interest because it was from recovered from Nagwada's earliest occupational phase, which immediately precedes the Harappan Period

at the site (Hegde et al. 1988: 62). Certain ceramics forms are found in this level and in equivalent contexts at several other sites in general vicinity (Dholavira, Sukotada, Moti Pipla – Figure 12.7), which exhibit close similarities to those used by the Early Harappan Amri-Nal and/or Kot Dijian peoples of southern Balochistan and Sindh (Possehl 1999: 603-609). These finds probably reflect the initial expansion of those cultures into the northern Gujarat area (Possehl 2002b: 40-41). If the silver used by Early Harappan peoples was extracted from lead ore as some have proposed (discussed in Chapter 4), then it will be of great interest to know whether or not the lead in the Nagwada ring is isotopically more analogous to the closest deposits of argentiferous lead in southern Rajasthan (specifically, the Zawar deposit and the Rampura-Agucha/Rajpura-Dariba belt – beginning around 225 km to the northeast of the site) or to the next nearest sources in the Khuzdar region (around 700 km away), which just so happens to be the northern part of the Amri-Nal culture area.

Lead was non-destructively extracted from five silver items excavated at Mohenjo-daro (Figure 12.25), which are currently on display at the National Museum in Karachi. The silver bangle sampled (NM-1) was one of two from a jewelry hoard (Marshall 1931b: Plate CXLVIII *in hoard*, Plate CLXIV b *restored*) found in a "Late Period" (roughly equivalent to Harappa Period 3C) room in the DK area (Mackay 1931a: 250, 1931c: 529). The other silver items sampled – a button or nose stud and three tiny beads on a strand of 18, are from the same excavations but are not specifically identified in the site report.

Prof. Walter Fairservis discovered a jewelry hoard at the small Harappan site of Allahdino, in southern Sindh (1993: 109). Ten silver items from that hoard (Figure 12.26) were sampled at the Department of Archaeology and Museum's head office in Karachi.

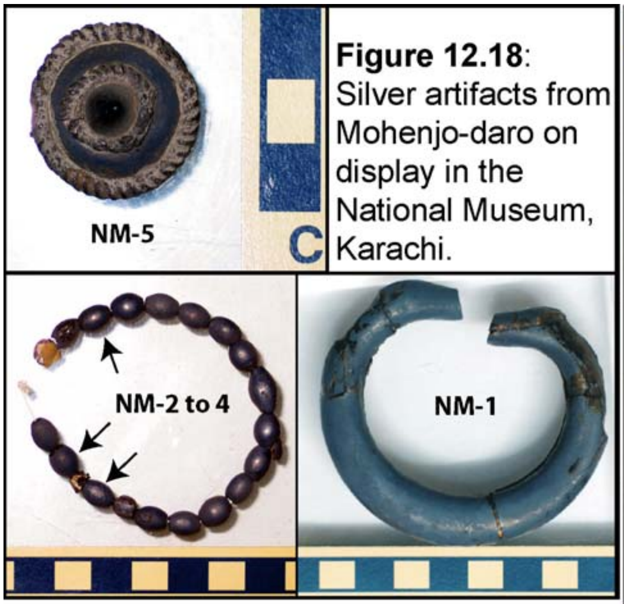


Figure 12.18: Silver artifacts from Mohenjo-daro on display in the National Museum, Karachi.

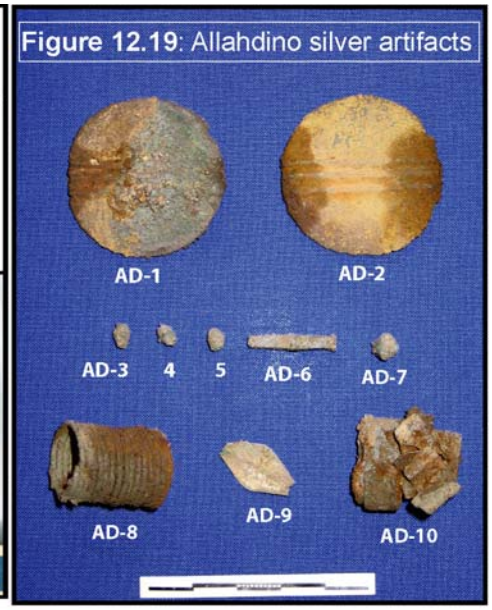


Figure 12.19: Allahdino silver artifacts

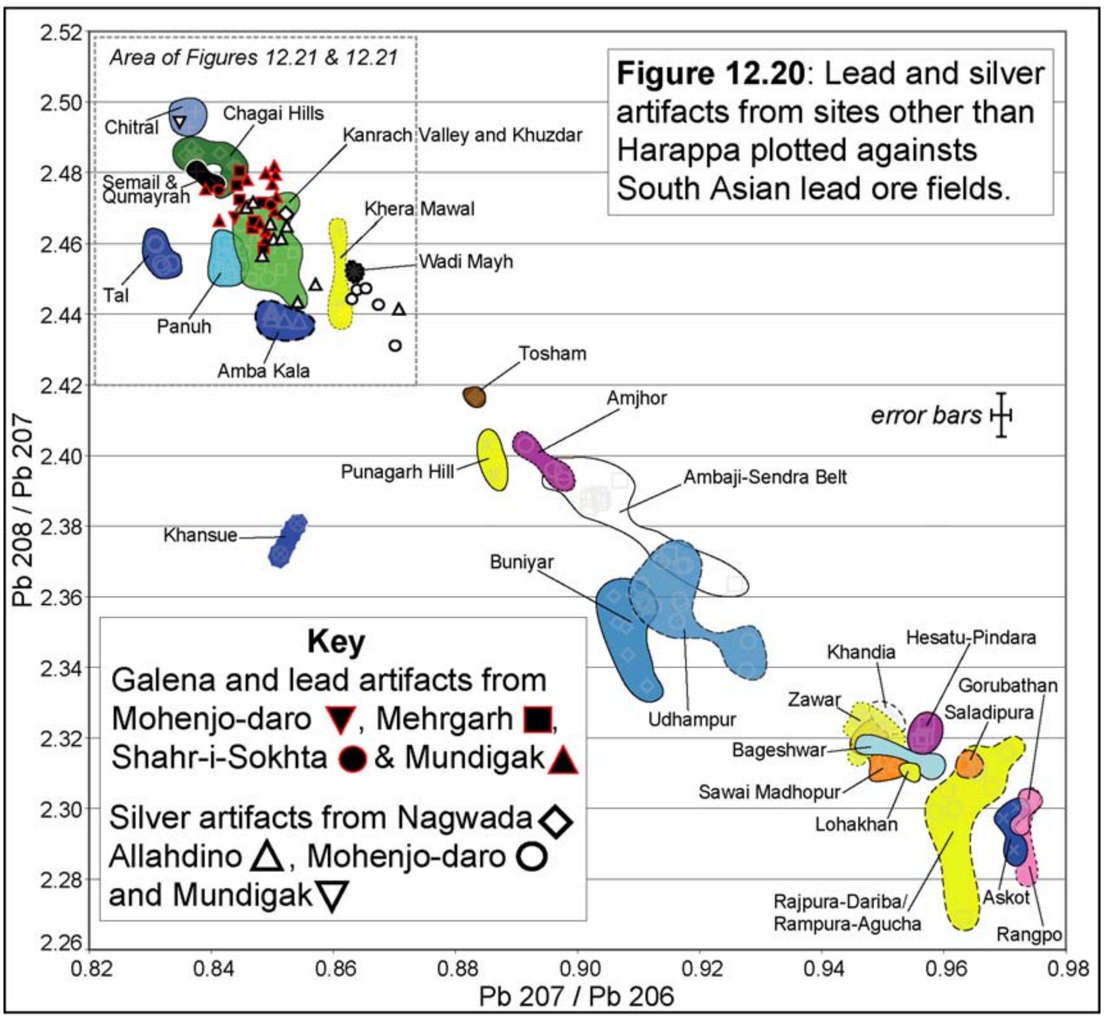


Figure 12.20: Lead and silver artifacts from sites other than Harappa plotted againsts South Asian lead ore fields.

Results

When the results of the Pb isotope analyses (appendices 12.4 and 12.5) of the lead and/or silver artifacts from the seven sites discussed above are placed on the bivariate plot of South Asian lead ore sources (Figure 12.27), all cluster in the upper left corner of the plot in two of the same general areas that many of the lead artifacts from Harappa previously fell. None appear to be even remotely related to sources in Jammu or Kashmir or to the many sources in Rajasthan (Khera Mawal excepted). Because all of the artifacts cluster in one section of the plot and a great many of them overlap, I have created two separate figures – one for lead (12.28) and one for silver artifacts (12.29), which focuses closely in on the area around where they fall. On these plots I have also placed the Pb data that was extrapolated (Appendix 12.6) from Stos-Gale's published (2001) isotope assays of galena samples from the well-known argentiferous lead deposit at Nakhlak in central Iran.

Lead artifacts

On Figure 12.28, twenty-five lead artifacts from five sites have been plotted in relation to select ore sources in South Asia, Oman and Iran. Before I begin to discuss the possible geologic provenience of those artifacts, first note that the *error bars*, when viewed from this closer perspective, are naturally much larger. Whereas on the previous bivariate plots the three areas where artifacts tended to fall/cluster were separated by distances that were far greater than the analytical uncertainty of the results, here many of the individual artifacts and groups of artifacts that I discuss are situated, relative to one another, within or near the range of possible error. Nevertheless, many artifacts cluster in distinct groups (rather than spread widely and randomly) that appear to be genuine and meaningful.

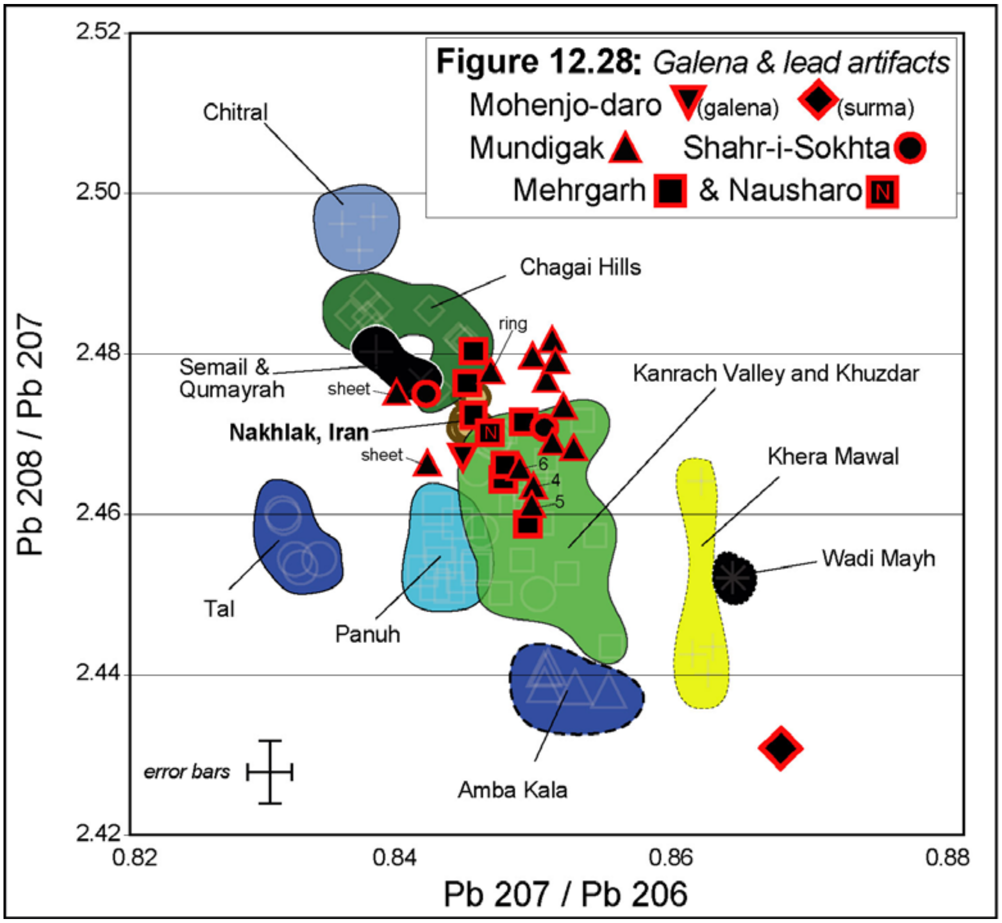


Figure 12.28: *Galena & lead artifacts*

Starting with the Mohenjo-daro lead artifacts, we see that the single galena fragment from that site plots on the margins of the southern Balochistan source area. The cluster of Nakhlak (Iran) source samples is within the range of analytical error. However, given the location of the site, it is far more probable that the archaeological ore originally came from the former region. The lead extracted from the "surma" bottle falls in the "ambiguous" area where several ores, artifacts and slags from Harappa have previously plotted. Still, it would seem that the lead-based substance that was once in that bottle came from a different source area than that in the substances once held in similar bottles at Harappa or the galena fragment just discussed. It is, of course, possible that lead from

multiple sources are present in the residue and what is we are seeing is an isotopic value plotting along a mixing line.

The Nausharo lead ring and most of the Mehrgarh galenas plot in an extended linear group, the majority of which fall within the area defined by the southern Balochistan sources. A few of the galena fragments, however, continue along the linear trend into areas where the Nakhlak and the Chagai Hills samples lie. It is difficult to judge whether or not the Mehrgarh galenas represent ores from a single source or multiple ones, although the linear manner in which they group indicates it may be the former. Perhaps when additional geologic samples from deposits in western Balochistan (Chagai region) are analyzed they will begin to isotopically overlap with the southern Balochistan deposits or vice versa. Although I doubt any of the archaeological ores actually came from the central Iran source (given that it is nearly 1400 km away and there were many other deposits that were closer), it is quite conceivable that Chagai Hills galena found its way to the Bolan Pass region.

The Mundigak lead artifacts plot in interesting ways. Of the ten galena fragments, seven (all of the unlabeled Mundigak data points on the figure) fall into a loose linear group (which may or may not represent a single source) that partly overlaps with the southern Balochistan deposits and then extends into an area where none of the geologic samples in the lead database lie. The three remaining Mundigak galenas (labeled by numbers 4 through 6) plot squarely within the southern Balochistan source area, with the Mehrgarh-Nausharo samples just discussed. Admittedly, given the degree of analytical uncertainty at this level, all of these lead ore artifacts could in reality be isotopically more similar (or dissimilar) than is evident here. However, I believe there are probably at least

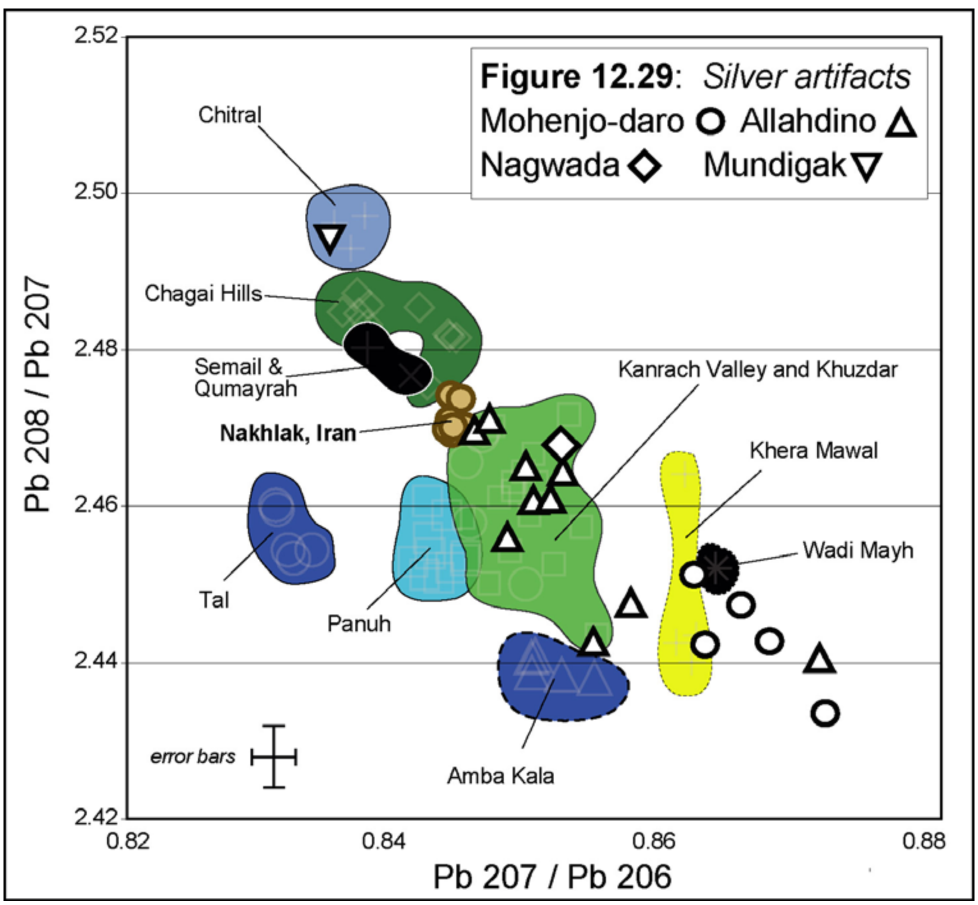
two sources represented among the Mundigak ores. Refer back to Figure 12.23 A for a moment. Although it is difficult to tell from the black and white image of the samples, the white weathered exteriors (probably cerussite) of artifacts MGK-04, 05 and 06 set them apart from other galenas, which have yellowish exteriors. These three ore fragments, which were excavated together, could actually be from a southern Balochistan source while the group of seven might be from the Asad Qala mine nearby Mundigak (samples from that deposit will eventually need to be analyzed in order to confirm this). The lead ring and sheet fragments (noted on the figure) plot differently still. Isotopically, the ring falls on the margin of the area defined by the Chagai Hills source samples and lies adjacent to a few of the Mehrgarh galenas. The lead sheet fragments fall well away from the other Mundigak artifacts – one is adjacent to two Oman data points while the other plots alone nearby. The sheets have a white oxidized exterior like MGK-04 through 06 and could be mixture lead from the same ore source and one or more others that are presently unknown.

Next we consider the two galena fragments from Shahr-i-Sokhta in eastern Iran. One of them plots in the area defined by the southern Balochistan source samples. However, it also groups closely with the cluster of Mundigak ores that *may* have been acquired from a deposit in the vicinity of that site. The second fragment falls in an area where data points for galena samples from both the Chagai region and Oman lie. It is entirely possible that the two ores could have actually have come from any of these areas. Close ties between Shahr-i-Sokhta and Mundigak clearly existed during the Integration Era of the Helmand Tradition (Shaffer 1992); the lead deposits in the Chagai region of western Balochistan are the closest (≈ 200 km) sources of that metal to the site; graves with Nal

culture jars in the cemetery area at Shahr-i-Sokhta (Piperno 1979: 125) suggest connections with southern Balochistan; and there is good evidence that long-distance trade relationships extended as far as the Gulf region and Oman (Ratnagar 2004: 66-67). Unfortunately, the lead deposits in the most pertinent region, Iran, are either poorly characterized or (mostly) not characterized at all. Making a stronger statement about the provenience of these artifacts is, therefore, not possible at this time and, as I will discuss, it may not be possible using Pb isotope data alone and/or using an ICP-MS to make isotopic measurements.

Silver artifacts

Now we move on to the 17 silver objects from four sites. The data for these are plotted on Figure 12.29 in relation to select lead sources in South Asia, Oman and Iran.



The ring from Mundigak plots with the three samples from the Shi Shi Valley lead occurrence in Chitral, NWFP. I believe it unlikely, however, that the silver for this item was extracted from that particular lead source as it somewhat "off the beaten path" and is not reported to be argentiferous (Tahirkheli et al. 1997). Certainly more accessible to residents of Mundigak would have been the silver-bearing lead deposits in the Ghorband and Panjshir valleys of north-central Afghanistan (Collins 1894; Pascoe 1931: 675). Those sources are located along the major trade and communication routes crossing the Hindu Kush of northern Afghanistan (Howland 1940) and, although unassayed, occur in the same general geologic terrain as the Chitral deposits. Of course, it is also possible that the ring contains lead from multiple sources and that its evident isotopic characteristics are a reflection of that rather and an individual deposit.

The data point for the Nagwada silver ring fragment falls within the area encompassed by the southern Balochistan lead deposits. Although it is possible that the isotopic characteristics of this artifact actually reflect the mixing of lead from multiple sources, it is very unlikely that one of those was the argentiferous deposit at Rajpura-Dariba in southern Rajasthan, which is situated at the opposite end of the bivariate plot of the main ore sources (refer to Figure 12.27). The only deposit anywhere in Rajasthan or Gujarat with isotopic characteristics that remotely resemble those of the lead in the ring is the small occurrence at Khera Mawal. However, even from the closer perspective used for the plot of silver items (Figure 12.29), the artifact and the data points for that source are separated by a distance greater than the range of possible analytical error. A geologic provenience of southern Balochistan for this silver ring from the initial occupation of

Nagwada is very much consistent with other evidence for the movement of Early Harappan peoples from that region and Sindh into northern Gujarat during the early third millennium.

The five silver items sampled from Mohenjo-daro plot in a loose group around the somewhat ill-defined area where so many lead artifacts from Harappa have also fallen. The bangle is adjacent to both the single Wadi Mayh (Oman) deposit data point and those for the Khera Mawal samples. The three beads group nearby. The button/nose stud plots slightly farther away but still in a manner that seems to suggest that it and the others ornaments are very possibly composed of metal containing lead (either natural or added) from the same source or sources. As far as I have been able to determine, neither the Khera Mawal or Wadi Mayh deposits are known to be argentiferous and, therefore, the probable geologic source of the silver used to make these items remains "ambiguous."

Eight of the ten silver ornaments from the Allahdino hoard plot within the area defined by geologic samples from the southern Balochistan lead deposits. Of the two remaining pieces, one – AD-9 (number 9 on the figure), falls with the five Mohenjo-daro silver artifacts in the "ambiguous" area. The other – AD-6, could simply be an outlier of the southern Balochistan deposits (AD-5 lies nearby, within that defined area). On the other hand, AD-6 (and perhaps AD-5) might be on an isotopic mixing line between one of those deposits and the ambiguous "source" where AD-9 and the Mohenjo-daro items fall. Or it may be from silver extracted from a different source area, one that is not represented in the database. Whichever the case actually is, the isotopic characteristics of the lead in most of the Allahdino samples are analogous to the sources of that metal closest to the site itself. Still, it is important to note that two examples (AD-1 & AD-8) fall near (within the range of

analytic uncertainty) the Nakhlak argentiferous lead deposit of central Iran and one (AD-5) lies similarly near to the Amba Kala deposit (also argentiferous) of Himachal Pradesh.

Interpretation of the Pb isotope data for lead and silver artifacts from all sites

Pb isotope assays have been made on 77 lead and/or silver artifacts from Harappa and seven other prehistoric sites in the Indus Valley and Helmand regions. When the results for all are placed on the bivariate plot of lead ore deposits (Figure 12.30) the data points representing them cluster in three main areas. Based on these patterns of clustering, the "probable geologic provenience" of each lead artifact from Harappa is stated in the final columns of appendices 12.2 and 12.3.

Those artifacts that cluster in the Pb isotope fields defined by the geologic samples from the Jammu and Kashmir region (Buniyar and Riasi area deposits) are, at present, the most secure in terms of their geologic provenience associations. With the exception of a slight degree of overlap with the Ambaji-Sendra belt (which, in actuality, is due to just two data points that are distant outliers of the main group of Ambaji-Sendra belt assays), there are no lead sources in the database with isotopic characteristics that even remotely resemble this one. Of course, this may eventually change as more sources are analyzed. Until that time, however, I believe it can be stated with a high degree of confidence that the lead in these particular artifacts probably came from sources in "Jammu and Kashmir."

Conversely, the artifacts with the least secure geologic provenience associations are those that cluster in what I have repeatedly called the "ambiguous" area around the Wadi Mayh, Khera Mawal and Amba Kala deposits. Although many fall next (or are within the range of analytic error) to the data points for those three deposits, I am reluctant to make

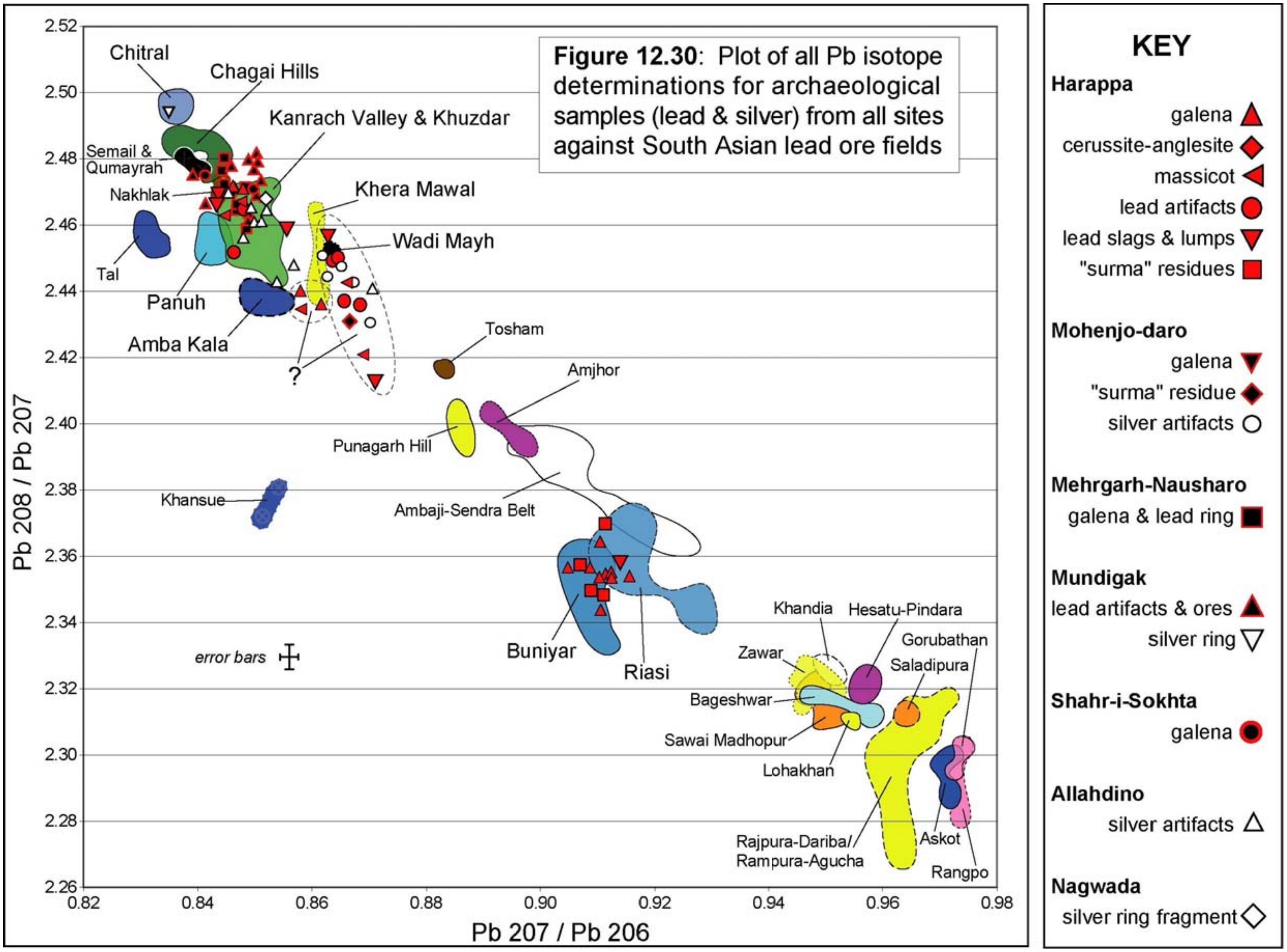


Figure 12.30: Plot of all Pb isotope determinations for archaeological samples (lead & silver) from all sites against South Asian lead ore fields

even a provisional provenience association for any of them because the "isotopic space" in this area so poorly defined in relation to known geologic sources. The characteristics that cause most of these artifacts to plot in this space *could* be due to the mixing of lead from two or more sources. Even if that is so, however, we may be certain that at least one geologic deposit with the same general isotopic characteristics as the artifacts in this cluster also exists and was exploited, simply because several of those artifacts are raw ores of lead (galena and massicot fragments from Harappa) that have not been subject to source mixing. In fact, there is probably more than one geologic deposit represented in this cluster and I have placed dashed ellipses on the figure around the areas where I think they could be. These ellipses are purely speculative and only further characterization of the geologic deposits around them (as well as of new ones) will allow us to determine if the artifacts that they group genuinely belong together. So although some of these lead and silver items may possibly come from sources in Oman, southern Rajasthan or Himachal Pradesh, for the Harappa artifacts I can only state that their geologic proveniences are "unclear at this time"

Artifacts in the third cluster are the most difficult to interpret. They fall mainly in the area, or "field," defined by the Khuzdar and Kanrach Valley lead deposits. Some, however, extend beyond that field and plot on or near data points belonging to samples from deposits in Iran, Oman and the Chagai region, as well as into areas of the bivariate plot that are not currently defined by any geologic sources. Those that do this belong to either the Helmand Civilization sites of Mundigak and Shahr-i-Sokhta, where residents may have been exploiting some of the lead sources in the regions around their settlements, or to Mehrgarh, which may have been acquiring lead through long-distance trade networks

extending to some of those very same source regions. It seems then almost certain that multiple geologic deposits dispersed across a wide geographic area are represented among the lead and silver artifacts making up this cluster.

The "fields" that are located in the section of the bivariate plot where artifacts in the third cluster fall are, at the present time, fairly distinct, i.e., there is minimal overlap between them. However, as additional ore samples from these and other sources are incorporated into the database there is reason to expect that they will begin to overlap with one another considerably more. That reason is because the geologic age (the principal factor influencing isotopic composition) of most of the metallogenic zones in which lead (and copper) is found in Balochistan, eastern Iran, southern Afghanistan and even Oman are *broadly* similar (Bazin and Hübner 1969; Samani 1998; Shams 1995b; Wolfart and Wittekindt 1980). One of the purposes for including data from the Nakhlak deposit of central Iran was to illustrate just how isotopically alike lead deposits from those different regions can be. An artifact with measured Pb isotope values causing it to plot with the Nakhlak data points would be still be within the range of analytic error to sources in Oman, southern Balochistan and the Chagai Hills region (Figure 12.29 shows this best). Admittedly, Pb isotope measurements made using an ICP-MS do leave something to be desired (namely, extremely high precision and useable ^{204}Pb values) when attempting to assign artifacts to sources within the limited isotopic space that this cluster encompasses. TIMS-generated data would undoubtedly improve source resolution in this part of the bivariate plot by lowering analytic uncertainty and providing a third dimension for comparison. However, as the database of assayed deposits in the Indo-Iranian highlands

and Oman increases, no amount of precision will enable one to differentiate overlapping areas that are isotopically identical. This could limit the ability to use Pb isotope data alone to identify the provenience metal artifacts from sites located within those regions.

The situation is entirely different for Harappa and sites in the Indus Valley because, as previously discussed, they are surrounded by regions in which the isotopic characteristics of the metallogenic zones within them are, on the whole, extremely different from one another. The precision provided by the ICP-MS is more than sufficient to differentiate artifacts coming from one regional zone or another. So as for the probable provenience of the artifacts from Harappa and other Indus sites that are among the third cluster under discussion, all fall into the field defined by the Khuzdar/Kanrach Valley data points. Although this field may eventually be obscured by data from other deposits, for now we can state, with a good degree of confidence, that the lead for those artifacts was acquired from nearest isotopically analogous sources – those in "southern Balochistan."

The same may be stated of the Nagwada ring and most of the silver artifacts from the Allahdino hoard. Although it is certainly possible the metal for those ornaments was extracted from isotopically analogous lead deposits in a different area (perhaps coming to the Indus region through trade with Mesopotamia as Ratnagar has suggested [2004: 199]), I believe that, with these new findings, the evidence that southern Balochistan was a silver source for Indus Civilization peoples is now fairly good. At least one of the Khuzdar occurrences (Gunga) is known to be highly argentiferous (Shams 1995b: 246) and sediment surveys of nalas (streams) coming off of the Mor Range in the lower Kanrach Valley area detected elevated levels of silver suggesting that the existence of sources in this region are

quite good (Naseem 2002). Old lead mines and smelting areas are well-documented around Khuzdar area (Hassan 1989; Siddiqui and Sharp 1993) and the only silver artifacts reported in this region are from Sohr Damb/Nal (Hargreaves 1929), which is in vicinity of Gunga and these old workings. The Early Harappan Nal and Indus Civilization era Kulli occupations at that site and in the southern Balochistan highlands provide the cultural links through which silver could have made its way to Allahdino in lower Sindh and Nagwada in northern Gujarat. Short of discovering archaeological remains that document the cupellation of silver from lead deposits in this area, the evidence (isotopic, artifactual and circumstantial) that at least some Harappan silver likely came from southern Balochistan sources cannot get too much better.

Copper

The focus of this chapter now shifts to copper, which was undoubtedly a material of enormous importance not only for Indus Civilization peoples but also for their contemporaries in many parts of Asia and Europe. Only through a concerted research program that combines isotopic and compositional analyses with stylistic and contextual studies (*a la* the recent work by Lloyd Weeks [2004] on copper alloy artifacts from Bronze Age sites in the United Arab Emirates) will it be possible to begin to fully understand the exploitation, production, trade, use and re-use of this metal at Harappa and elsewhere in ancient South Asia. My intention here is not that ambitious. In this section, I use Pb isotope analysis to compare the few examples of raw copper ore that have been recovered at Harappa to a small database of isotopic assays made of geologic samples and copper production debris (slags) representing sources in five broad regions from which Indus

Civilization peoples may have acquired this important metal. Although this study is small in size, it is the first direct analytic comparison of copper artifacts from Harappa to geologic materials from potential sources since Sana Ullah's early work (1940).

Copper ore at Harappa

Only seven copper minerals have been identified from among the more than 2600 copper or copper-alloy artifacts recovered at Harappa. In addition, the only vitrified craft indicators related to this metal are things like crucible and kiln-wall fragments that are made of clay-based materials (Miller 1999: 414). The scarcity of ores and the absence of siliceous slags is indicative of production activities that involved melting and working metal that had already been processed in some way rather than the smelting of raw copper ore in order to extract metal (Miller 1994b: 505). This is not at all surprising. It certainly would have made little sense to transport large amounts of raw ore over 400 km to the site (the minimum distance to deposits of any significance) when it could have been reduced to easily manageable quantities of metal at or closer to its source. The seven ores (Appendix 12.8) – four small fragments of chalcocite and three of malachite (examples can be seen in Figure 4.3 E); all come from the south slope of Mound E, which is where the heaviest concentration of copper production debris was found (Miller 1999: 414-415). All are from surface or disturbed contexts except for a single malachite fragment from Period 3C levels.

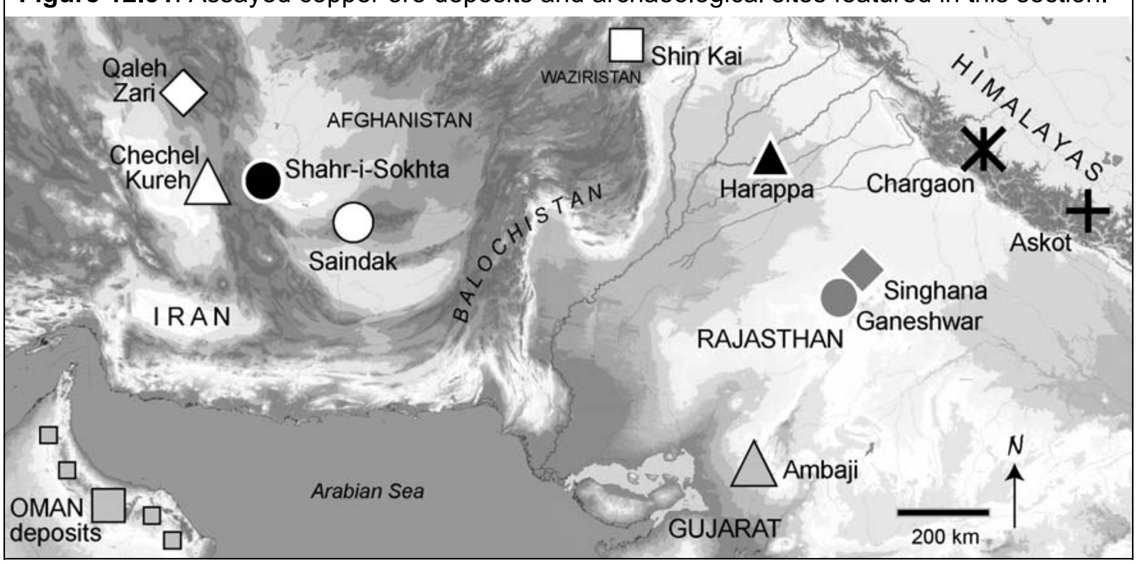
The Pb isotope database for copper ore sources

Kenoyer and Miller suggested (1999: 115) that Harappan metalsmiths might have acquired copper from deposits in four main source regions: the broad region west of the Indus Valley that includes the combined areas of Balochistan and Afghanistan; Oman; the

Aravalli mountain range of Rajasthan and northern Gujarat; and, perhaps, Iran. I basically agree with this but would add a fifth region – the Himalayas and related highland areas of northern India and Pakistan, as a potential source area, especially since it now appears that some of the lead found at Harappa was acquired from deposits in Jammu and Kashmir.

Prior to this study, Pb isotope assays of copper ores had only been made for deposits located in Oman, Iran and the Aravallis. The database (Appendix 12.7) presented here includes isotope values extrapolated from those previously published data along with new analyses of copper ores and/or slags from seven locations in Balochistan, Waziristan, the Himalayas and the Aravallis. Below, I focus mainly on the assayed the deposits that are featured in the database (Figure 12.31). For more comprehensive overviews that detail individual occurrences and the many old workings found in these regions see the following: for Pakistan and India (Ahmad 1969; Chakrabarti and Lahiri 1996; Geological Survey of India 1994; Kazmi and Jan 1997; Nandan et al. 1991); Afghanistan (ESCAP 1995: Peters et al 2007); Iran (Bazin and Hübner 1969); and for Oman (Weeks 2004).

Figure 12.31: Assayed copper ore deposits and archaeological sites featured in this section.



The Aravallis

The Aravalli Range of Rajasthan and northern Gujarat is considered by many to have likely been one of the main sources (some believe *the* main source) for the copper used by Indus Civilization peoples (Agrawal 2000; Agrawala 1984; Allchin and Allchin 1982; Asthana 1993; Chakrabarti and Lahiri 1996; Dhavalikar 1997; Kenoyer and Miller 1999; Pascoe 1931; Sana Ullah 1940). Nineteen major zones of base metal mineralization occur intermittently along its approximately 600 km length and old workings have been noted in every one of them (Geological Survey of India 1994). The richest deposits are found in the northern part of the range in the zone known as the Khetri "Copper Belt." Although it was not possible to obtain ore samples from deposits within this zone, copper smelting slags from two locations were provided by Kishore Raghubans, a PhD student at M.S. University, Baroda who is doing his dissertation research on the Ganeshwar-Jodhpura culture complex, which was an indigenous, non-urbanized Chalcolithic society inhabiting the northern Aravalli region during the third millennium BC (Agrawala and Kumar 1982). The first set of slags was acquired at Singhana (near Khetri), where the numerous small hills (heaps) composed entirely of smelting debris provide an indication of the intensity and duration of the copper extraction/production activities that have taken place in this region (Figure 12.32 A & B). The second set comes from a smelting area located less than one kilometer from the site of Ganeshwar, where more than 5000 of copper artifacts were recovered from third millennium BC levels (Hooja and Kumar 1997: 328). From here and from other Ganeshwar-Jodhpura culture settlements along the Khetri copper belt, Harappan consumers would have been living only from 100 to 150 km away in the southern Haryana.

Figure 12.32: Copper workings in the Aravalli Mountains of Gujarat and Rajasthan.

A & B. Enormous copper slag heaps at Singhana near Khetri, northern Rajasthan



C & D: Old smelting area and wall made of slag near Ambaji, northern Gujarat



In 1985, Hegde and Ericson conducted Pb isotope assays of single chalcopyrite samples from five deposits in the Aravallis. The values produced for two of those samples (from Khetri and Kho Dariba) were not even remotely comparable to other Pb isotope determinations made for massive sulfide deposits in the Aravallis or, for that matter, to any

typical Pb-Pb isochron (Dickin 2004: 149-151). Until the accuracy of those particular cases can be confirmed they will not be used. Hegde and Ericson's published values from the other three samples do, however, appear to be accurate. The datapoint for a chalcopyrite sample from the Ambaji deposit (discussed below) is consistent with both the previously published TIMS data (Deb et al. 1989) and the analyses that I have made on samples from that occurrence. Details on the two remaining assayed deposits (Kankaria and Piplawas) are scarce but they are reported to be located in the central portion of the Aravalli Range.

The Ambaji polymetallic (Pb-Zn-Cu) sulfide deposit is located in the southernmost portion of the Aravalli Range. Old pits and slag fields extending for several kilometers can be found in this area (Figure 12.32 C & D), which lay only 150 km to the northeast of the Harappan site of Nagwada. Literary evidence and C^{14} dates from beams in deep (480 m) disused mine shafts suggest that ore has been extracted here since at least the first century BC (Nandan et al. 1981: 58). Previous isotopic characterizations of this deposit were made using galena samples (Deb et al. 1989). Although the isotope values were expected more or less identical, new assays of ten chalcopyrite samples collected from the Gujarat Mineral Development Corporation's open pit mine at Ambaji were made for this database.

The Himalayas

Geologists conducting fieldwork in areas of the Himalayas ranging from Kashmir to Uttaranchal have noted hundreds of old mine shafts, open pits and/or slag heaps related to the extraction and production of copper (Dass et al. 1964; Middlemiss 1929; Nandan et. al 1981; Sharma 2002). Dr. D.P. Agrawal correctly observed (1999) that this broad region has largely been overlooked in past studies of ancient metallurgy and he singled out the

extensive polymetallic sulphide deposit at Askot in eastern Uttaranchal (previously discussed in the relation to the lead ore database) as an important potential source for ancient consumers of copper in the northern part of the Subcontinent. The seven assays from this location in the copper database were made on samples provided by Dr. Rajesh Sharma of the Wadia Institute of Himalayan Geology, Dehra Dun.

Chalcopyrite (reported as pyrite – Director - Punjab Haryana and Himachal Pradesh Circle - Geological Survey of India 1971: 188) occurring in a granite pegmatite was collected near Chargaon in the Kinnaur District, Himachal Pradesh (N 31° 30' 55", E 78° 07' 10"). Although this mineral appeared to be a minor accessory ore in what is reported as an old lead-silver mine (neither of those metals were located, however), five assays were included in the database because they are the only other copper minerals from a Himalayan deposit, besides those from Askot, that I currently had in my possession. There are many, many other potential copper sources across this region remaining to be characterized.

Sources west of the Indus Valley

Porphyry copper deposits of *broadly* similar geologic ages are found across the western Balochistan – eastern Afghanistan regions (Afghanistan Geological Survey 2006; Chmyriov et al. 1973; ESCAP 1995; Ludington et al. 2007; Sillitoe 1978). One of the largest occurs in Cretaceous to Oligocene era island arc volcanic rocks in Balochistan's Chagai district (Ahmad 1975: 40-46; Shams 1995b). The extensive slag fields found in that region (Vredenburg 1901: 292) and directly to the north in the Gardan Reg area of southwestern Afghanistan (Dales 1971; Dales and Flam 1969) bear testament to the intensive exploitation of these deposits during the early to mid-third millennium BC

(Kenoyer and Miller 1999). Seven ore samples from the Saindak occurrence (Wolfe 1974) were provided by Abdul Razique and Razzaq Abdul-Manan of Tethyan Copper Ltd.

Copper occurrences are also found in the ophiolite sequences that were emplaced during the Cretaceous to Lower Eocene eras along the western margins (the "Indus suture zone") of the Indus Basin at various points from the NWFP to Balochistan (Asrarullah et al. 1979). Several prospects are located within the Waziristan ophiolite (Badshah 1985), around 60 km up the Tochi River from where Neolithic and Early Harappan settlements of the Bannu Basin lie (Khan et al. 1988). In June of 2001, chalcopyrite and malachite was collected for this study from the Shin Kai prospect (≈ N 32° 55', E 69° 52') near Mohammad Khel (Badshah et al. 1997). Several minor deposits of the same nature are also found in the Zhob ophiolite (Heron and Crookshank 1954: 58-59) some 150 km to the south-southwest.

One potential source of copper from which samples have not yet been acquired for this study but is still very much worth mentioning here is the Las Bela ophiolite of southern Balochistan. "Massive copper sulphide prospects" are found between 15 to 30 km northeast of Uthal town at Saap and Ann Dhoros (Ahsan and Quraishi 1997: 44-45). Although these are said to have "no economic value" (ibid.) by today's standards, they are quite likely the very same places "in the hills between Liari and Bela" where 19th and early 20th reports indicated copper could be found in "large quantities" (Gazetteer of Las Bela 1907: 118). Del'Hoste (1844) related a colorful account by two Hindu traders who said that they had easily smelted a good quantity of the metal from this source before they were run out of the area under threats from the local tribal chief of being "burned alive" if they returned.

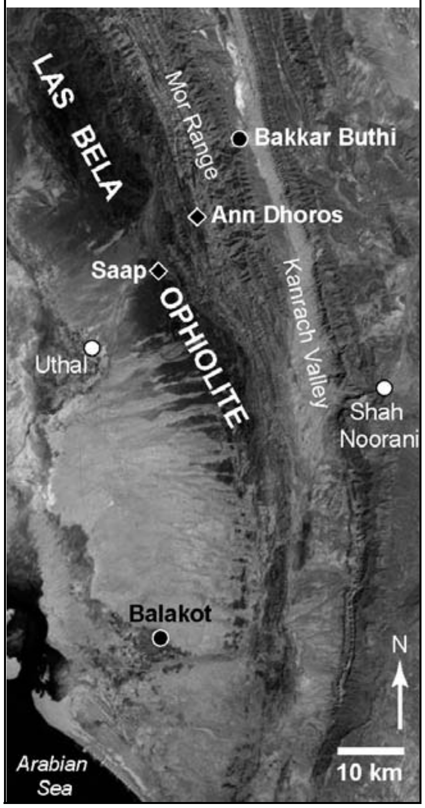


Figure 12.33: Copper deposits and towns (Harappan and modern) in relation to the Las Bela ophiolite

Although they are trifling in relation to copper deposits in most of the other source areas discussed in this section, the Las Bela ophiolite occurrences are important because there were permanent Harappan settlements located in the vicinity (Figure 12.33). Bakkar Buthi lies just 20 km to northeast across the Mor Range and Balakot is situated around 50 km due south. All of the other potential sources are in regions external to the "core area" of Indus Civilization sites. Although it is unfortunate that I am not able to include samples from these deposits in the copper database, it still may be possible to examine them by proxy. Although the lead deposits in the Kanrach Valley are hosted in Jurassic sedimentary rocks, the mineralization is thought to be associated with the Las Bela ophiolite zone (Zaigham and Mallick 2000: 487). The isotopic character of the copper deposits *might*, therefore, be similar to those of the Kanrach Valley galena samples.

Iran

The copper deposits of Iran are numerous, widespread and have evidently been exploited since antiquity (Bazin and Hübner 1969: 4-6; Berthoud et al. 1976; Wertime 1968). For Indus Civilization consumers, however, they would have been rather remote – the nearest are more than 1,100 km west of Harappa as the crow flies. Hauptmann and others recently (2003) conducted a Pb isotope analysis on samples from two copper

deposits in eastern Iran (Chechel Kureh and Qaleh Zari) and set of copper ores, slags and artifacts from Shahr-i-Sokhta. The isotopic values for the archaeological ores (which have been included in this database along with those for the two geologic deposits) most closely matched those of the samples from the Qaleh Zari source, 300 km northwest of the site.

Oman

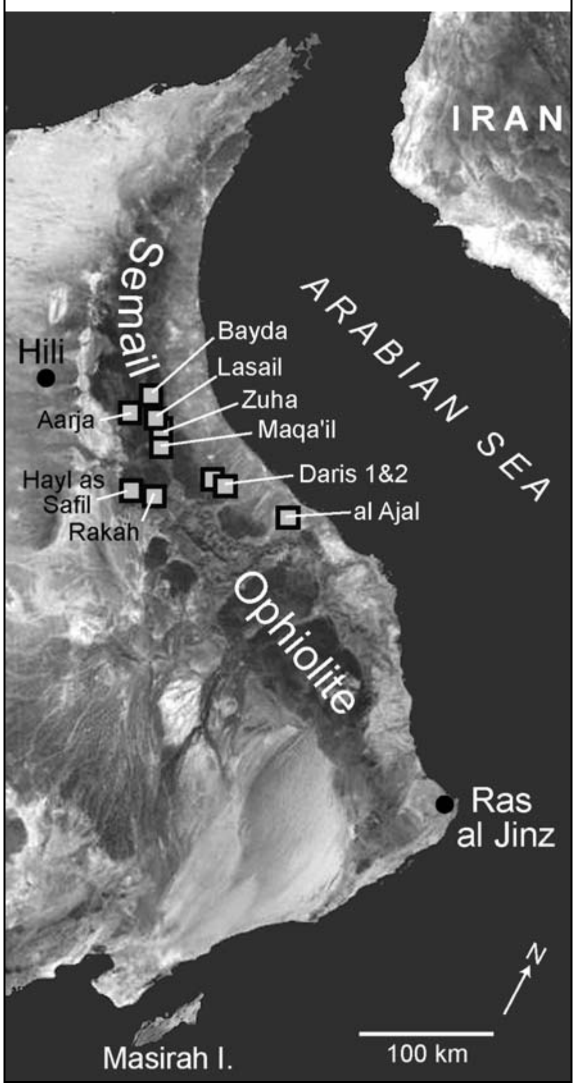


Figure 12.34: Isotopically assayed massive sulphide deposits and sites having Harappan materials in Oman

The exploitation and production of copper by the ancient peoples of the eastern Arabian Peninsula region (Figure 12.34) has been the subject of much study (Berthoud and Cleuziou 1983; Craddock et al. 2003; Prange 1999; Weeks 2004; Weisgerber 1984). Some feel that metal from deposits in Oman made its way to Harappan consumers (Kenoyer and Miller 1999) while others are doubtful that the region was an important source (Agrawala 2000; Chakrabarti 1998). The existence of trade links between the Indus Valley and this region are not in doubt, however. Harappan artifacts have been found at coastal settlements like Ras al Jinz (Cleuziou and Tosi 1994) and at inland oasis sites like Hili (Cleuziou and Vogt 1985).

Most copper in Oman occurs in massive sulphides deposits within ophiolites that are located either on the mainland of the eastern Arabian Peninsula (the Semail ophiolite) or on Masirah Island, just off of the country's southeastern coast (Weeks 2004: 12-14). Non-ophiolitic deposits exist but are minor in nature (ibid.). Pb isotope analyses of massive sulphide ores (usually chalcopyrite or pyrite) from eleven deposits in this region have been conducted by Chen and Pallister (1981) and Calvez and Lescuyer (1991). The assayed deposits include one non-ophiolitic source (al Ajal) and ten occurrences within the Semail ophiolite (location names are in the second column of Appendix 12.7 and on Figure 12.34).

Analysis and results

In addition to the seven copper ore fragments from Harappa, Pb isotope assays were made for 49 ores and/or slags from deposits in each of the potential source areas discussed above. Ore samples (archaeological and geologic) were brought into solution by dissolving 0.02 grams of fresh material from them in ultra-pure nitric acid. Slag samples (15 each from Singhana and the smelting area near Ganeshwar) were crushed into a coarse powder and then examined under low magnification for any minute copper prills that could be used for analysis. When no metal could be found or the sample weight could not be reached, the siliceous part of the slag was used. Many examples had patches with a distinct greenish cast, which were preferred for analysis because the coloring was presumably due to copper content. Although the sample weight for some the slags was doubled to 0.04 grams in an effort to get more lead into solution, in exactly half of those analyzed there was still too little of it for the ICP-MS to make accurate measurements. In the end, Pb isotope data was obtained for 11 of the 15 Ganeshwar slags but only for four of the slags from Singhana.

The ores and slags analyzed at the LARCH, together with the previously published Pb isotope values, provide 85 datapoints representing copper deposits in the five potential source areas being considered here. When their ratios are placed on a bivariate plot ($^{208}Pb/^{207}Pb$ to $^{207}Pb/^{206}Pb$) along with those of the seven archaeological copper ores from Harappa, they spread widely, clustering in three areas (Figure 12.35). The chalcopyrite samples from Chargaon mine in Himachal Pradesh cluster in the upper left portion of the plot while those from the polymetallic sulphide deposit at Askot, Uttaranchal fall at the other extreme in the bottom right corner. Plotting along with the latter group are the datapoints for the assays that Hegde and Ericson (1985) conducted on samples from the Kankaria and Piplawas copper deposits of central Rajasthan. All of the remaining source samples, along with the ores from Harappa, fall in a cluster of largely overlapping groups in the center of the plot. The isotopic characteristics of the artifacts are clearly much different from either of the two Himalayan sources or the samples from central Rajasthan. This does not mean, however, that the Harappan ore fragments could not have come from other copper occurrences in those regions – just not these particular deposits or, most probably, not from any other deposits that are geologically related to them.

For Figure 12.36, the area of the main cluster in which the Harappan artifacts fall has been enlarged. Starting from the bottom left of the plot; the datapoints for the Ambaji mine in northern Gujarat cluster in a fairly well-defined group and are consistent with the single assay that Hegde and Ericson (1985) conducted for that deposit (noted on the plot with “H&E”). Although two Singhana slag samples representing the Khetri copper belt of northern Rajasthan fall nearby, most from that zone (including the Ganeshwar slags) cluster

Figure 12.35: Pb isotope ratios for seven copper ore fragments from Harappa plotted against the ratios for samples (ores & slags) from seven copper sources in South Asia and Oman

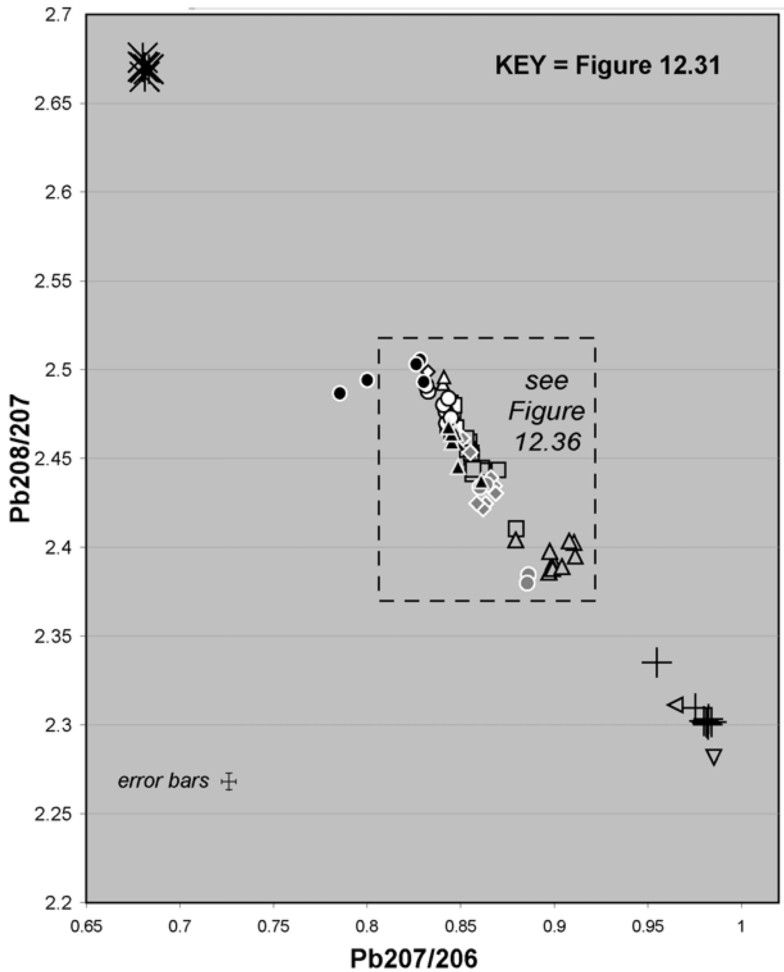
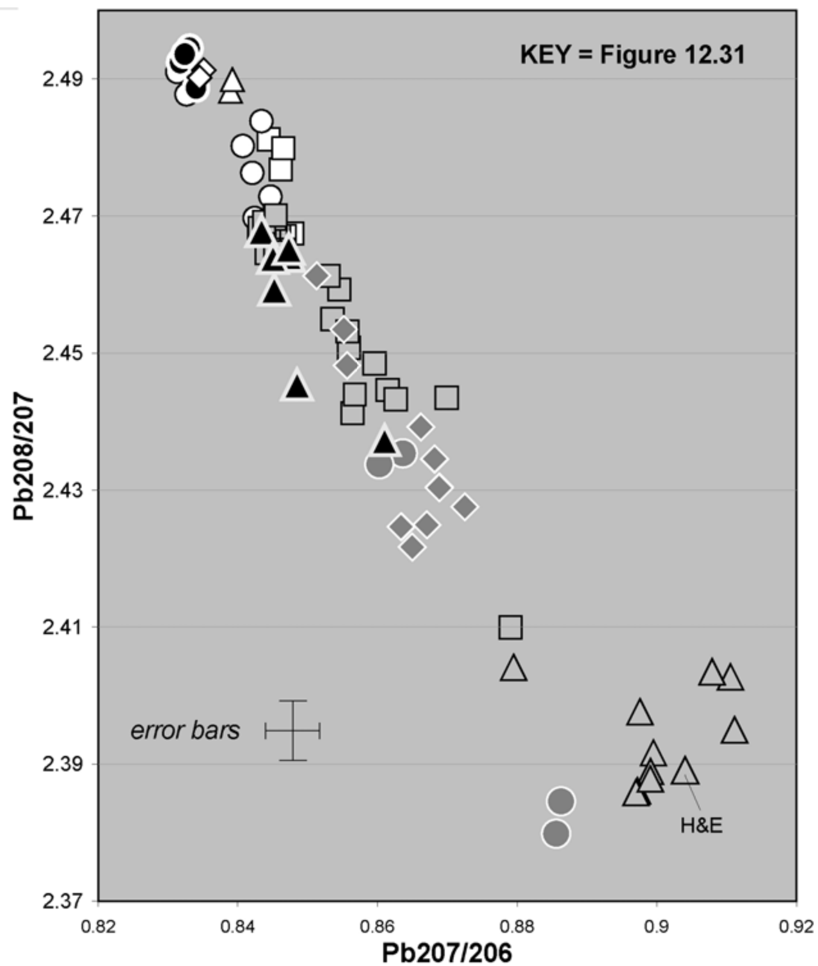


Figure 12.36: Pb isotope ratios for seven copper ore fragments from Harappa plotted against the ratios for samples (ores & slags) from select copper sources in South Asia and Oman



higher to the left, in the middle of the plot. From that point begins the area where most of the datapoints for the various Oman sulphide assays fall. Three of the Ganeshwar slags plot there as well. The Oman assays terminate in a tight group (it is difficult to see on the plot but there are nine data points there) exactly at the point where the linear clusters of the Shin Kai (Waziristan) and Saindak (Chagai) datapoints begin, overlapping with several of them. The latter two groups extend from there to the point where the Iranian ore samples (geologic and archaeological) begin, with two of the Saindak datapoints overlapping with the Shahr-i-Sokhta artifacts and Qaleh Zari deposit samples.

The datapoints for five of the seven copper ores from Harappa fall upon (or directly adjacent to) the small area where the Oman, Chagai and Waziristan samples overlap that. This is most definitely a situation where having high precision isotope ratios and useable ^{204}Pb values might be of great benefit in helping to differentiate sources and resolve the provenience of artifacts. Or it might not. The Waziristan and Semail ophiolites both formed in the mid-to-late Cretaceous era (Gnos et al 1998; Weeks 2004: 9) as did some of the older intrusive volcanic rocks that host the Saindak deposit (Shams 1995b: 243-244). Therefore, these massive sulphide occurrences (and others, like the occurrences in the Zhob and Las Bela ophiolites, of roughly equivalent age) and porphyry copper deposits ultimately may be indistinguishable using Pb isotope data alone. Of the remaining two Harappan ores; one plots with two of the Singhana slags (but within the range of error to the Oman cluster) and another falls parallel to but apart from where some of the Oman samples and Ganeshwar slags group. The former could be from the Khetri copper belt but I

would feel more confident in such an assessment if 1) the samples representing that source were ores rather than slags and 2) the analytical precision were better than it is.

It is possible to state that the Harappan ores probably do not come from those deposits in the database representing eastern Iran, southern Rajasthan or the Himalayas. Five of them could be from sources in Oman or from geologically similar deposits located in regions to the west of the Indus Valley like Waziristan or western Balochistan. Of the remaining two, the provenience of one is unclear (perhaps it comes from Western sources also) while the other *may* have come from the Khetri copper belt of northern Rajasthan.

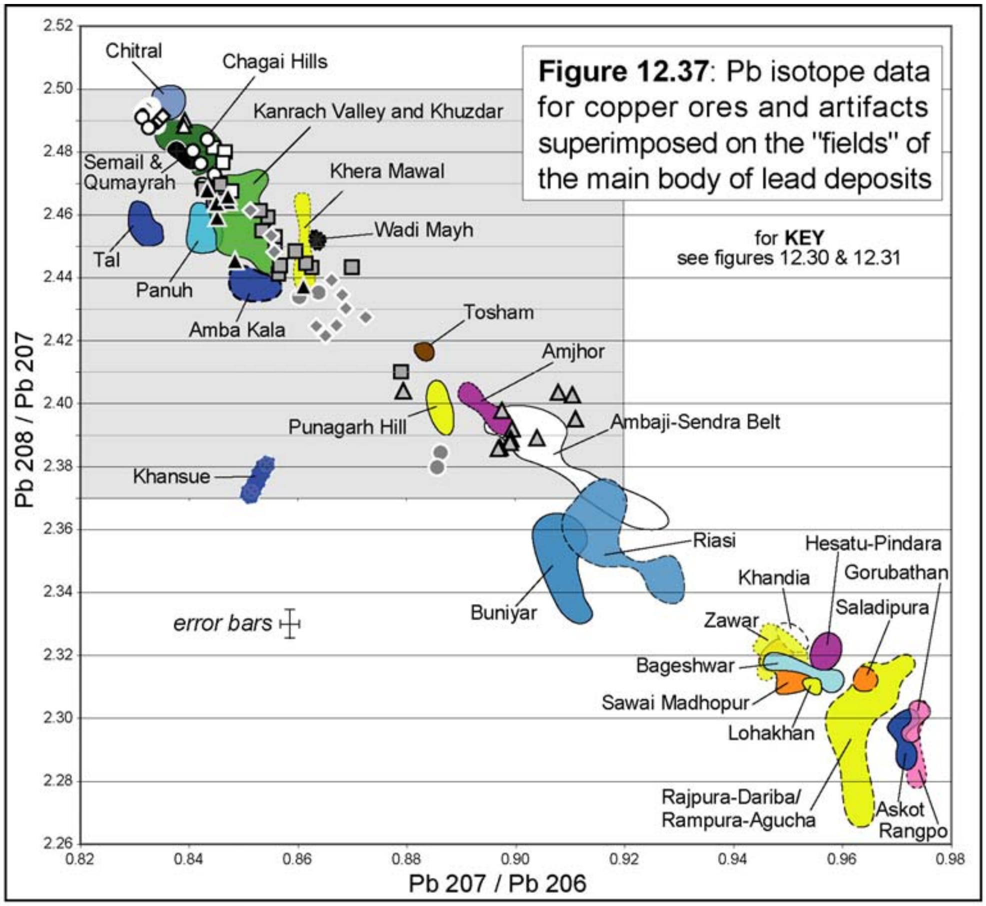
Comparison of the lead and copper datasets

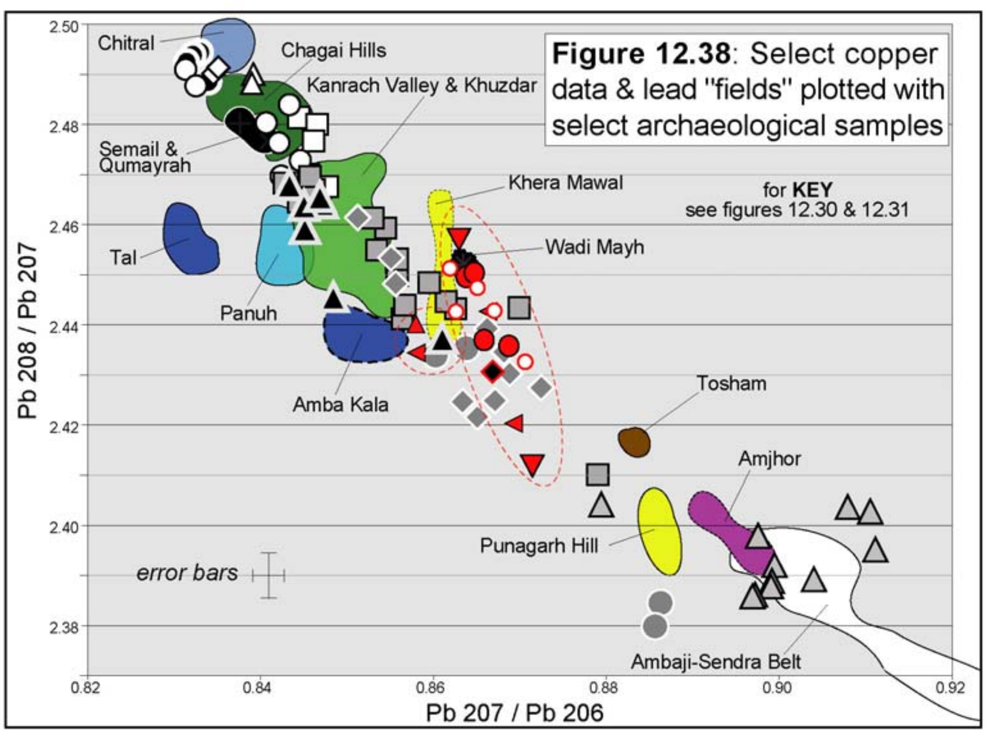
Many of the metal ore sources featured in this chapter are dominated by either lead mineralization or copper mineralization – e.g., the Kanrach Valley (lead) and Khetri (copper) deposits. Other sources, like Ambaji and Askot, are rich in both metals. Rather than trying to evaluate all metal artifacts in relation to sources with very different and complex geologies, a decision was made early on in this study to treat lead and copper separately, the idea being, as it were, to compare apples-to-apples and oranges-to-oranges. So, two databases were assembled that contained Pb isotope assays made one just one or the other type of material rather than including all analyses made for a metallogenic zone or deposit. For instance, Calvez and Lescuyer (1991) produced Pb isotope data for galenas, copper-bearing massive sulphides, gossans, pelagic sediments and volcanic rocks from locations in northern Oman. The galena assay values from that study went into the lead ore database and the sulphides into the copper database – the rest were excluded. However, now that the main comparative studies are complete, it may prove informative to briefly

evaluate the databases in relation to one another and to compare certain artifacts to both of the databases combined.

In Figure 12.37, I have superimposed the Pb isotope data for the main cluster copper sources and artifacts (Figure 12.36) directly on the bivariate plot of the main body of lead ore fields. All of the copper data falls in the upper left quarter of the plot. This area is enlarged for Figure 12.38, where I have also added the data points and dashed ellipses for those lead artifacts that clustered in the "ambiguous" area of the lead deposits database.

The first thing that is evident from these plots is the way in which the Pb isotope assays of copper and lead samples from the same metallogenic zones, not at all unexpectedly, tend to correlate well with one another. The copper samples from the Saindak deposit (white circles with black borders) in the western Chagai District of Balochistan plot either on or directly adjacent to the isotope field (dark green) defined by galena fragments from related porphyritic deposits (Rekodiq and Koh-i-Sultan) located nearby. Copper and lead samples from the Ambaji mine similarly correlate with one another. In future versions of these databases, assays of both copper and lead minerals from these sources and others like them can probably be safely used together. It remains to be determined whether or not the same will be true for lead and copper deposits found within a common metalliferous zone or just located in the same regions. However, because the two databases are far from being complete, it is worth the effort to briefly consider where certain lead and copper artifacts plot in relation to geologic samples in the opposite databases (i.e. lead-to-copper and copper-to-lead). This might, at least provisionally, help to fill some of the existing isotopic "gaps" or "ambiguous areas."


Figure 12.37: Pb isotope data for copper ores and artifacts superimposed on the "fields" of the main body of lead deposits
for KEY
see figures 12.30 & 12.31
Chitral
Chagai Hills
Kanrach Valley and Khuzdar
Semail & Qumayrah
Khera Mawal
Wadi Mayh
Tal
Panuh
Amba Kala
Tosham
Amjhor
Punagarh Hill
Ambaji-Sendra Belt
Khansue
Riasi
Hesatu-Pindara
Khandia
Gorubathan
Buniyar
Zawar
Saladipura
error bars
Bageshwar
Sawai Madhopur
Lohakhan
Rajpura-Dariba/ Rampura-Agucha
Askot
Rangpo
Pb 208 / Pb 207
Pb 207 / Pb 206


Figure 12.38: Select copper data & lead "fields" plotted with select archaeological samples
for KEY
see figures 12.30 & 12.31
Chitral
Chagai Hills
Kanrach Valley & Khuzdar
Semail & Qumayrah
Khera Mawal
Wadi Mayh
Tal
Panuh
Amba Kala
Tosham
Amjhor
Punagarh Hill
error bars
Ambaji-Sendra Belt
Pb 208 / Pb 207
Pb 207 / Pb 206

Note that on Figure 12.38 the five copper ores from Harappa that cluster closest together, all plot within the isotope field for the southern Balochistan lead deposits (and a sixth falls adjacent to it). Most of the galena samples defining that field are from occurrences in the Kanrach Valley, which (as discussed above) may be geologically (and isotopically) related to the nearby Las Bela ophiolite and the copper-bearing sulphide deposits within it. Even if those copper and lead deposits are shown to be isotopically analogous it would not rule out the other possible sources (Oman, Waziristan, Chagai) for the archaeological ores. It would, however, establish the southern Balochistan region as an isotopically analogous source area in which both copper deposits and Indus Civilization settlements can be found.

Consider also the various lead artifacts from Harappa and silver artifacts from Mohenjo-daro (noted on Figure 12.38 as white circles with red boarders) that cluster in the "ambiguous" area on the bivariate plot of lead sources. Many of the slags representing the Khetri copper belt also plot in that area. Although this is an interesting association, it must be examined realistically. Lead mineralization is exceedingly rare in this part of northern Rajasthan. One of the few occurrences that have been reported – trace galena in a deep coring at Saladipura (Deb et al. 1989), is isotopically very unlike the slags and the artifacts. Silver is extracted today from argentiferous copper ores in the Khetri belt (Rao et al. 1997). However, there is no evidence that it was exploited there during earlier eras, nor have any silver artifacts reported been reported from Ganeshwar-Jodhpura sites in the region. Still, although the chance that the metal for these lead and silver artifacts actually came from northern Rajasthan is very slim, it is important to keep an open mind to the possibility.

A final point to note is how, collectively, copper samples from sources in Balochistan, Oman and Iran form a linear swath of datapoints that plot across the isotope fields defined by lead samples from those same regions (and southern Afghanistan too if the Mundigak ores are used as proxy source samples). This illustrates the point I tried to make at the conclusion of the section on lead and silver – as more samples from more deposits across these regions are incorporated the database, there is almost certainly to be a significant degree of isotopic overlap between them. Perhaps with high precision TIMS measurements the sources in this part of the plot can be differentiated from one another but that is by no means certain. For metal artifacts from Indus Valley sites having Pb isotope characteristics that cause them to plot in this area it may, ultimately, only be possible to state that they probably came from sources to the west of the Indus Valley or from Oman.

Chapter conclusion

The Pb isotope measurements produced using the EDTA/ICP-MS method are, admittedly, not as accurate as those obtainable using other techniques. However, the method is more than accurate enough to differentiate lead and copper ores sources as isotopically diverse as those found in and around the Greater Indus region. Moreover, because of the ease of sample preparation and its non-destructive nature, many artifacts can be assayed that would otherwise be unavailable. In addition, the comparatively low cost of analysis means that large numbers of artifacts and, importantly, comparative geologic samples can be analyzed.

Much work remains to be done to create comprehensive Pb isotope databases with which to evaluate the potential lead and copper geologic provenience of artifacts from

Harappa and other archaeological sites in the region. With regard to sources that may have been utilized by Indus Civilization peoples, there are many deposits in the study regions that remain uncharacterized. There is currently no isotopic data for any metalliferous ore bodies in Afghanistan. The need to assay the lead deposits of Haraza, NWFP and copper deposits in Jammu and Kashmir is particularly acute as I have provided evidence in this chapter and elsewhere in this dissertation that Harappans were probably acquiring several rock and mineral varieties from these regions to the north of the site. One area, which I have not previously discussed in this chapter, where both lead and copper mineralization have been reported (Heron and Crookshank 1954 95-96; Siddiqui and Shams 1988: 3), is eastern portion of the Salt Range, just 230 km north of Harappa. This is, in fact, the source area *nearest* to the site for either of those metals! The copper mineralization is said to be trifling but the galena occurrences were apparently popular sources of surma for the local population (Punjab Government 1907: 204; Wynne 1878: 300-301). Obtaining and analyzing samples from this region is of the highest priority and their absence in the databases is another reason why the geologic provenience determinations made in this chapter should always be considered provisional.

In addition to expanding the databases to incorporate new sources, it will be equally important to produce many more assays on the deposits already in it. Currently, the average number of analyses per source is around five. It is generally held that at least 20 analyses of a lead ore field need to be conducted in order to adequately define its isotopic boundaries (Pollard and Heron 1996: 328). Still others have argued that having a bare minimum of 40 analyses is more realistic, especially when the isotope data for an ore field

are not normally distributed (Baxter et al. 2000). By those standards some sources in this database, such as the Rajpura-Daribia/Rampura-Agucha lead ore field, which has 31 data points, are fairly to very well characterized. Nearly all other sources in it are drastically under-characterized, with several even being represented by only a single data point. Even at this early stage, however, a great deal new has been learned with regard to the lead, silver and copper acquisition networks in which the residents of Harappa, as well as some of their predecessors and contemporaries at sites in the Greater Indus region and beyond, were involved.

We now know that Harappans were acquiring raw lead ore (galena) from the Jammu and Kashmir region at the time of the site's foundation (Ravi Phase) and were still doing so during the latter part of the urban phase (periods 3B and 3C). They apparently used some of the galena from this source to make surma. Residue in a surma bottle from Mohenjo-daro indicates residents of that site used lead from a different (unknown) source to make this cosmetic. During Period 3C, Harappans also appear to have been acquiring raw lead from at least two (possibly more) other regions. Cerussite-anglesite and massicot from sources in southern Balochistan (those near Sohr Damb/Nal in the Khuzdar district are strong candidates) were probably used as mineral pigments or cosmetics. Some of the galena used by people at Mohenjo-daro and the early residents of Mehrgarh may have also come from that region. Harappans acquired galena and massicot from at least one or more additional sources, the location(s) of which are not known at this time. These unknown sources do not appear to be the same ones that residents of the Helmand Civilization sites of Mundigak and Shahr-i-Sokhta probably exploited in southern Afghanistan and east Iran.

Harappans melted lead from all three regions (Jammu and Kashmir, southern Balochistan and the unknown source or sources) to fashion various kinds of items.

We also now know that the silver used by Indus Civilization peoples was being extracted from at least two different argentiferous lead ore sources. The Early Harappan settlers of Nagwada *may* have brought this metal with them from deposits in Balochistan (probably around Khuzdar) as they moved into northern Gujarat from regions to the northwest. The silversmiths who created the artifacts in the Allahdino hoard seem to have used some metal from deposits in that region as well. They also appear to have used metal from the same source(s) as those who made the silver artifacts analyzed from Mohenjo-daro. The location of that source is presently unknown, however.

Finally, we now see that residents of Harappa did not acquire a great deal of raw copper ore (malachite or chalcocite). Only seven examples have been recovered at the site to date. Most of these (5 or 6 of the 7) were probably derived from sources to the west of the Indus Valley or, perhaps, Oman. One ore fragment *may* have come from deposits in the northern part of Rajasthan's Aravalli Range. It will be important to eventually determine if a similar acquisition pattern exists for finished copper artifacts, which constitute a major part of Harappa's rock and mineral assemblage.

In the next chapter, I take the provenience determinations made for all of the lead artifacts and copper ores from Harappa and, together with the determinations made for each of the other materials examined in the preceding seven chapters, address the three lines of inquiry outlined in Chapter 1.

Chapter 13

Summary and discussion

Chapter 13 – Summary and discussion

Chapter introduction

The principal research objective of this dissertation was to locate the sources of the rock and mineral resources acquired by the ancient residents of Harappa. In Chapter 4, the site's entire stone and metal artifact assemblage was categorized into material varieties and then, using recent field observations and contemporary geologic reference materials (as opposed to century-old District Gazetteers), the most probable sources for the majority of them were outlined. Throughout the eight chapters that followed, selected varieties were directly compared to geologic samples collected from potential sources using a range of analytical methods. Over 2100 provenience determinations for artifacts from Harappa[1] were generated as well as almost 120 for artifacts from other sites. In this chapter, these data are summarized and brought to bear on the three lines of inquiry outlined in Chapter 1. The implications of the answers to those inquiries are discussed in the concluding section.

Summary

The results of this study are summarized in a series of maps on which symbols for identified and probable rock and mineral sources are plotted for each chronological period and sub-period at Harappa. When this is done, six detailed "pictures" (figures 13.2 through 13.7 corresponding to Harappa periods 1, 2, 3A, 3B, 3C and 4/5) emerge that approximate the extent of Harappan rock and mineral resource acquisition at different periods in time. Provenience data for artifacts from the other sites examined are summarized on Figure 13.8.

[1] Grindingstone (n = 1796), chert (n = 24), steatite (n = 140), agate (n = 24), vesuvianite-grossular (n = 7), limestone (n = 113), alabaster (n = 30), lead and copper (n = 36). *Total* = 2170.

Figure 13.1:
Key for figures 13.2 to 13.8



Figure 13.1 is the key for the maps. All rock and mineral varieties recovered from secure contexts at Harappa and the symbols representing them are listed. A symbol for silver, which appears only on the figure (13.8) detailing acquisition networks for other sites, was added to the key along with symbols for obsidian and nephrite, which are materials that may exist at Harappa but remain to be positively identified. On the maps themselves, resource acquisition is depicted with varying degrees of confidence. Solid lines from source symbols to sites denote acquisition networks based on firm provenience data. For example, the solid lines between the Rohri Hills chert source and Harappa drawn on the maps for periods 1 through 3B (figures 13.2 to 13.5) indicate that for each period at least one artifact was compared to samples from various chert sources and assigned to the Rohri Hills. Dashed lines depict networks that can still be reasonably inferred to have existed even though provenience data was not generated. For instance, although no tan-gray chert artifacts from Period 3C levels were analyzed, a dashed line was drawn from Harappa to the Rohri Hills for that period (Figure 13.6) based on the fact that identical looking artifacts from all previous periods were

assigned to that source. The pathways of all network lines are, of course, conjectural. When possible, line thicknesses were varied in order to approximate differential source use among certain varieties (recall on p. 407 how this was done for steatite). Symbols plotted alone (without network lines) denote sources that are argued – based solely on factors such as the extent of the culture phase that Harappans belonged to and the overall acquisition pattern, to have *perhaps* been utilized during particular periods. All statements made in the summaries below are based on data and other evidence presented in previous chapters.

Ravi Phase – Period 1 (ca. 3300 BC to 2800 BC)

No fewer than 14 rock and mineral varieties were brought to Harappa during the Ravi Phase (Figure 13.2). Steatite was obtained from sources in two regions – Jammu and the northern Aravalli Range. Although some chert was acquired from the Rohri Hills of Sindh and the west-central Salt Range, at this time a purple-hued chert-chalcedony that *perhaps* originated in areas of trap rock in the eastern Salt Range and/or Kashmir was mainly used. The majority of the grindingstones recovered came from the relatively nearby Kirana Hills. Only small amounts of the stone used to make querns and mullers came from the much more distant Sulaiman Range, Himalayan Foothills (Siwaliks) or the outliers of the Aravalli Range in southern Haryana. The sole Ravi Phase galena fragment recovered was derived from one of the lead deposits in the Jammu and Kashmir region. The one vesuvianite-grossular artifact (a flake) found came from an occurrence in the Mohmand Agency. Because the only viable lapis lazuli sources for Harappans would have been the Badakhshan deposits of northern Afghanistan, it can be very confidently stated that all lapis lazuli artifacts recovered from this phase (and subsequent ones) came from that region.

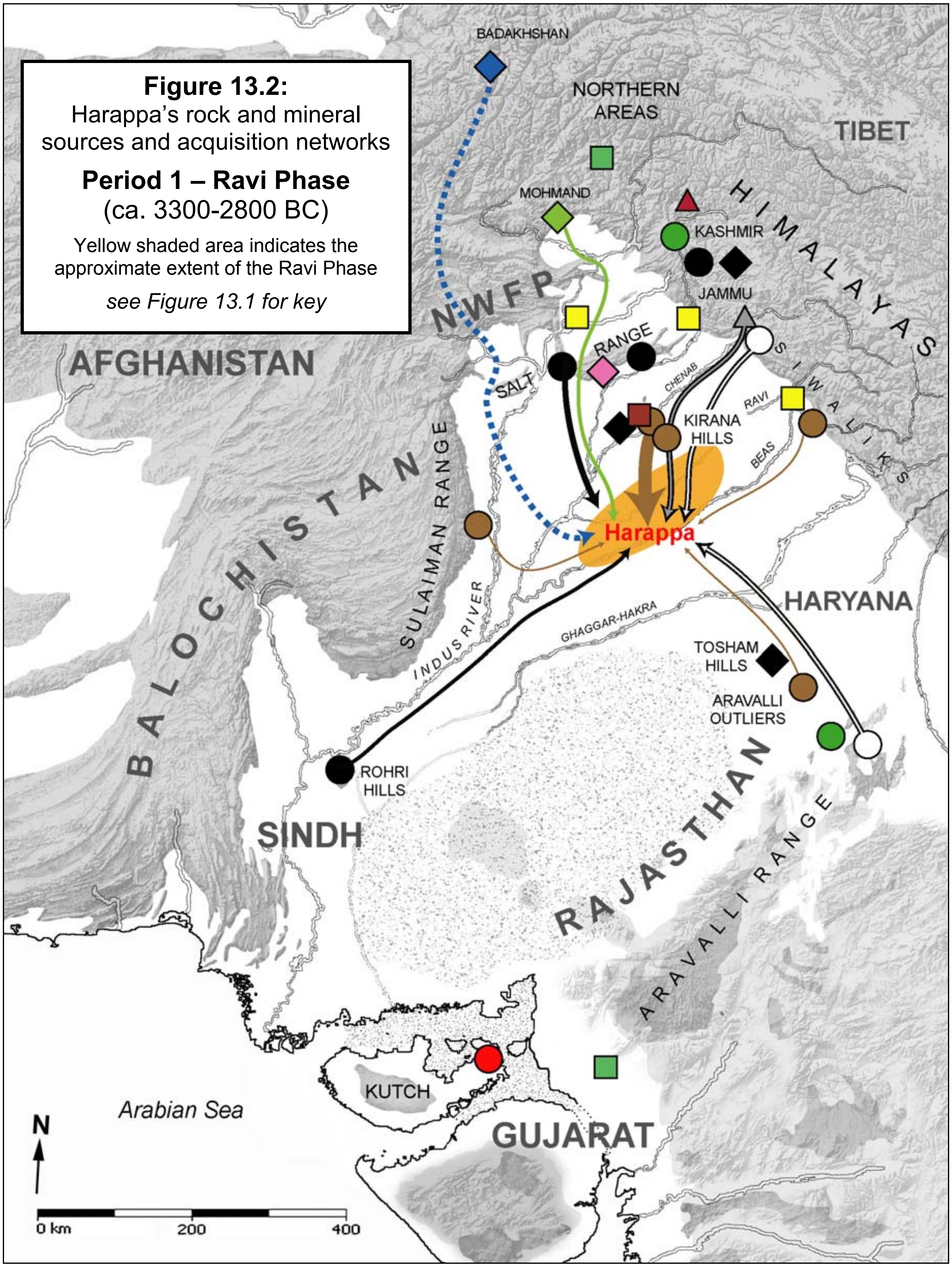


Figure 13.2:
Harappa's rock and mineral sources and acquisition networks

Period 1 – Ravi Phase
(ca. 3300-2800 BC)

Yellow shaded area indicates the approximate extent of the Ravi Phase

see Figure 13.1 for key

Provenience analyses have not been conducted on any of the remaining rock and mineral varieties recovered from Period 1. It is, however, reasonable to assume that many of them came from the same regions to the north of the settlement that Ravi Phase Harappans acquired (and from which Harappans of later phases would continue to acquire) a large portion of their raw stone and metal. Alabaster from Period 1 levels was probably derived from the same sources in the Salt Range used during periods 2 and 3. Gold was likely obtained from the rivers draining the Himalayas, which were the nearest sources and no doubt then much richer. Amazonite and almandine garnet may have come from Himalayan pegmatites along with igneous/metamorphic rocks. Some rocks of the latter variety, as well as ochre minerals, probably also came from the much closer Kirana Hills.

Copper might have come from one of the minor occurrences in the western Himalayas. However, they may also have been acquired from sources in other regions. The presence of steatite from the northern Aravalli Range opens the possibility that the rich copper resources of that region were accessible at this time. Additionally, some igneous and metamorphic rocks might have come from the Tosham Hills, which lie in the direction of the Aravallis. The presence of marine shell from the Arabian Sea coast during the Ravi Phase (Kenoyer and Meadow 2000: 67) suggests that the agate and, possibly, the amazonite sources of distant Gujarat may have also been accessible at this time.

Kot Diji Phase – Period 2 (2800 to 2600 BC)

Harappans acquired at least 14 varieties of rocks and minerals during the Kot Diji Phase (Figure 13.3). Steatite was now obtained exclusively from sources in regions to the north of the site – mainly from Jammu and the Hazara District of the NWFP but also from

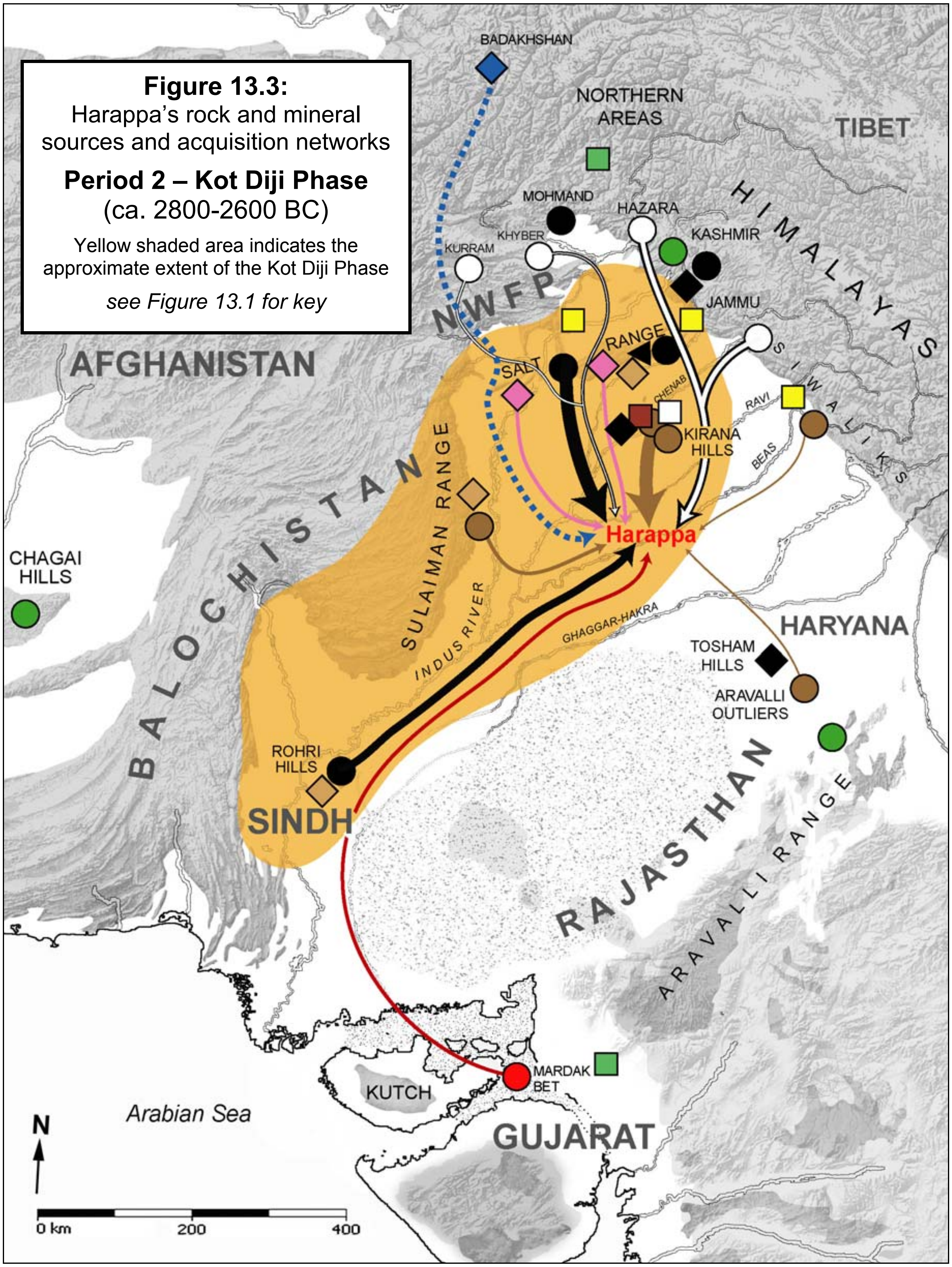


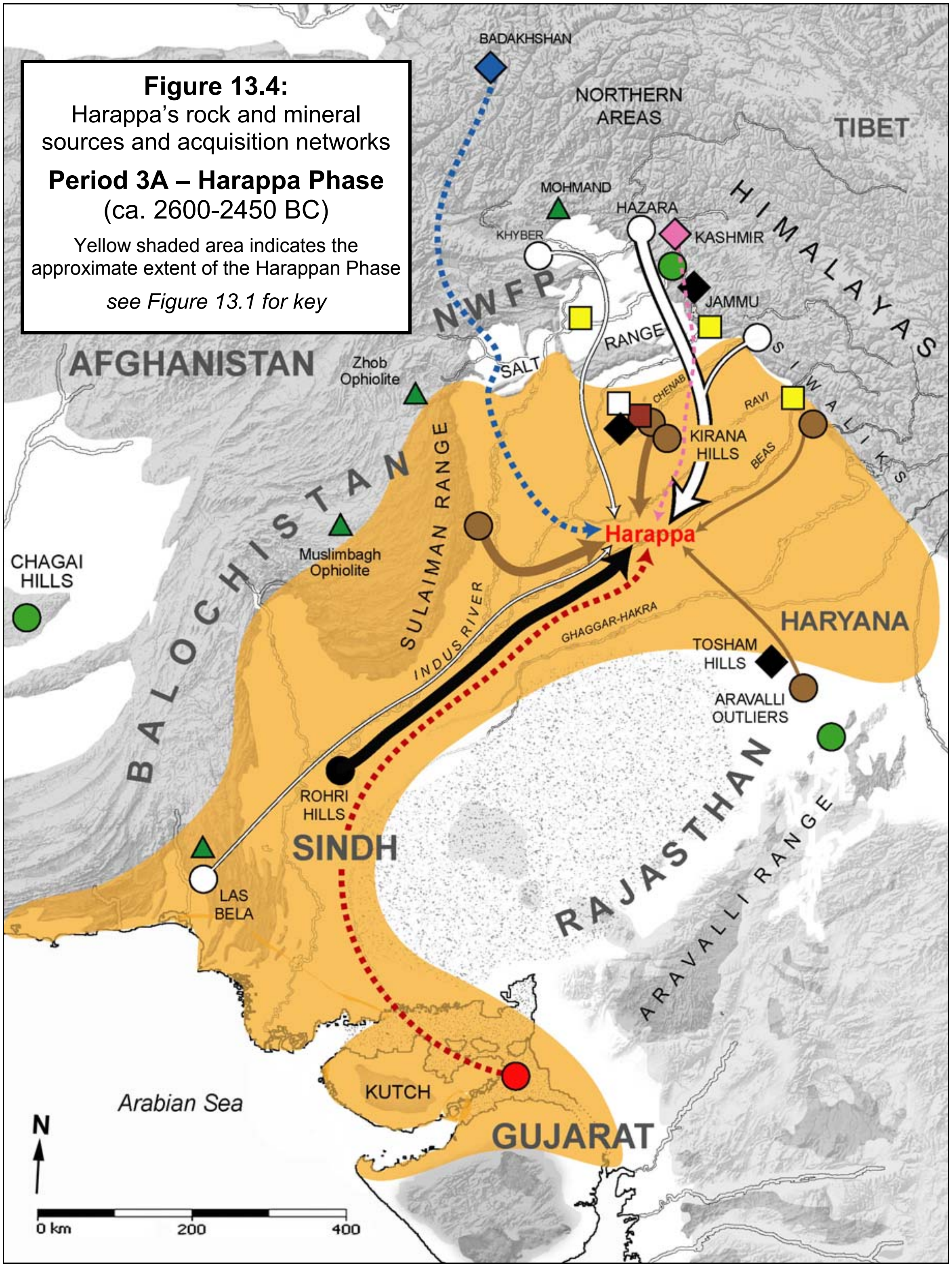
Figure 13.3:
Harappa's rock and mineral sources and acquisition networks
Period 2 – Kot Diji Phase
(ca. 2800-2600 BC)
Yellow shaded area indicates the approximate extent of the Kot Diji Phase
see Figure 13.1 for key
BADAKHSHAN
NORTHERN AREAS
TIBET
MOHMAND
HAZARA
KHYBER
KURRAM
KASHMIR
HIMALAYAS
JAMMU
NWFP
AFGHANISTAN
SALT
RANGE
CHENAB
RAVI
KIRANA HILLS
BEAS
SIWALIKS
BALOCHISTAN
SULAIMAN RANGE
Harappa
CHAGAI HILLS
INDUS RIVER
GHAGGAR-HAKRA
HARYANA
TOSHAM HILLS
ARAVALLI OUTLIERS
ROHRI HILLS
SINDH
RAJASTHAN
ARAVALLI RANGE
MARDAK BET
KUTCH
Arabian Sea
GUJARAT
N
0 km
200
400

the Khyber and Kurram agencies. The majority of the chert used at this time stillcame from the west-central Salt Range. However, increasing amounts were being acquired from the Rohri Hills and some *may* have been brought from the Mohmand Agency. The use of purple-hued chert-chalcedony was diminishing. Most querns and mullers were still being made from Kirana Hills stone. There was a slight increase in the amount of Pab sandstone from the Sulaiman Range being used to make grindingstones but materials from the Himalayan Foothills and the Aravalli outliers were still only acquired in very minor amounts. Alabaster was derived from sources in both the central and western Salt Range. At least some agate was acquired from a source (Mardak Bet) in northern Gujarat.

The likely sources for the remaining Kot Diji Phase rock and mineral varieties are, with a few additions, mostly the same as they were during the Ravi Phase. The limestone that first appears in Harappa's assemblage at this time is an extremely commonplace type (brown micritic). It might have come from the Salt Range along with chert, alabaster and, perhaps, obsidian. Or it could be from the Sulaiman Range or Rohri Hills. The situation is the same for quartz and rock crystal artifacts. Those may have come from the Kirana Hills or they could be from sources further a field. The broader cultural horizons of the Kot Diji Phase would have made many resources in distant regions, such as the copper deposits of western Balochistan (Chagai Hills area), much more accessible to residents of Harappa.

Harappa Phase – Period 3A (2600 to 2450 BC)

The twelve rock and mineral varieties recovered from the limited exposures of Period 3A levels (Figure 13.4) almost assuredly do not represent the full range of stone and metal resources acquired at that time. They do, nonetheless, provide evidence that some


Figure 13.4:
Harappa's rock and mineral sources and acquisition networks
Period 3A – Harappa Phase
(ca. 2600-2450 BC)
Yellow shaded area indicates the approximate extent of the Harappan Phase
see Figure 13.1 for key
BADAKHSHAN
NORTHERN AREAS
TIBET
MOHMAND
HAZARA
KHYBER
KASHMIR
HIMALAYAS
NWFP
JAMMU
RANGE
SALT
AFGHANISTAN
Zhob Ophiolite
SIWALIKS
CHENAB
RAVI
KIRANA HILLS
BEAS
SULAIMAN RANGE
BALOCHISTAN
Muslimbagh Ophiolite
Harappa
CHAGAI HILLS
INDUS RIVER
GHAGGAR-HAKRA
HARYANA
TOSHAM HILLS
ARAVALLI OUTLIERS
ROHRI HILLS
SINDH
RAJASTHAN
ARAVALLI RANGE
LAS BELA
KUTCH
Arabian Sea
GUJARAT
N
0 km
200
400

changes in acquisition patterns took place (or were taking place) around the time fully urban lifeways emerged at Harappa. The primary regional source of steatite was now (and would hereafter be) the Hazara District of the NWFP. Minor amounts of that stone were acquired from deposits in Jammu and the Khyber Agency as well as, for the first and only time, the Las Bela ophiolite of southern Balochistan. The serpentine artifacts that initially appear in Harappa's assemblage during this phase may have also come from the latter region or another with a similar geology (e.g., the Zhob, Muslimbagh or Mohmand area ophiolites). The Rohri Hills of Sindh appear to have been the sole chert source used by site residents at this time. Pab sandstone from the Sulaiman Range now slightly surpassed Kirana Hills stone as the most acquired type of raw material for making querns and mullers. There were also slight increases in the use of grindingstone from the Himalayan Foothills and northern Aravalli outliers. Agate (carnelian) was likely obtained from sources in Gujarat, just as it was in the periods that proceeded and followed this one. The isotopic characteristics of some of the alabaster artifacts from this period (and from periods 3B and 3C) suggest that they *may* have come from unanalyzed sources in Jammu and Kashmir.

Harappa Phase – Period 3B (2450 to 2200 BC)

Harappans were acquiring at least 19 rock and mineral varieties by the middle part of the urban phase – Period 3B (Figure 13.5). The Haraza District was again the primary source for steatite but some was also brought from Jammu, the Khyber and Kurram agencies and the northern Aravalli Range. Although most of the chert used at Harappa still appears to be from the Rohri Hills, there are indications that some *may* have been obtained from the Mohmand Agency, NWFP. This is certainly possible as vesuvianite-grossular was

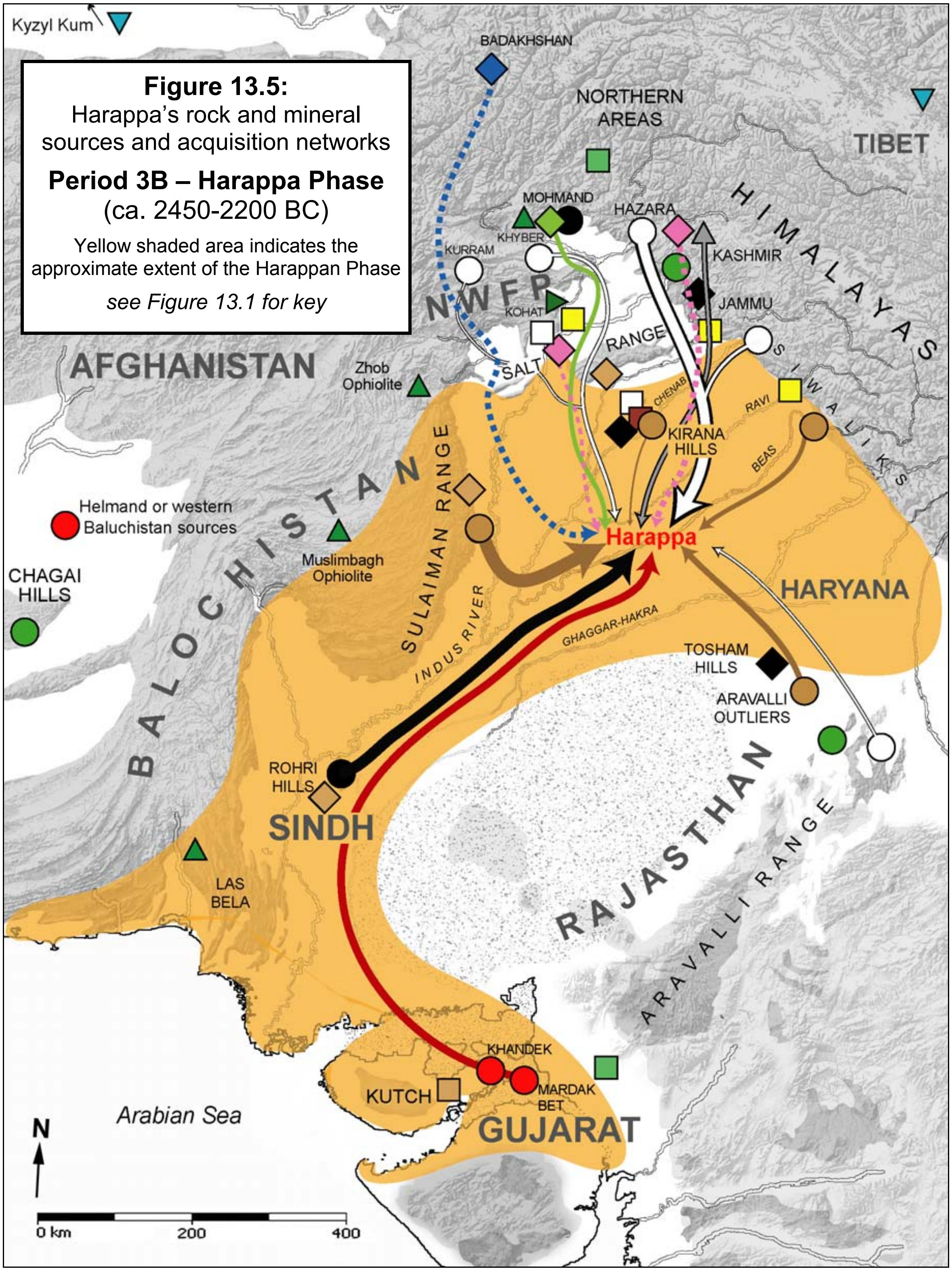


Figure 13.5:
Harappa's rock and mineral sources and acquisition networks
Period 3B – Harappa Phase
(ca. 2450-2200 BC)
Yellow shaded area indicates the approximate extent of the Harappan Phase
see Figure 13.1 for key

also being acquired from a source in that region. The lead in a lead-based cosmetic from a Period 3B burial came from a source in Kashmir, perhaps in the Buniyar area. The use of Kirana Hills stone for querns and mullers practically ceased during this phase. Although the acquisition of stone from the Himalayan Foothills and northern Aravalli outliers increased slightly over the preceding period, the majority (nearly 70%) of grindingstone was still brought from the Sulaiman Range. Agate was being obtained from two sources in northern Gujarat – Khandek in western Kutch and Mardak Bet in the Little Rann. Some *may* have also come from same sources used by residents of Shahr-i-Sokhta, which would most likely have been in the Helmand region or western Balochistan.

The recovery of Mari "Diamonds" – the bi-pyramidal quartz crystals that occur within certain massive gypsum deposits of the Salt Range, from Period 3B levels indirectly suggests that alabaster from that region was being acquired at the time. "Ernestite" first appears in Harappa's assemblage during this period and, although no occurrences of the stone have yet been located, the fireclay beds of Kutch in northern Gujarat are among the best candidates for sources. Turquoise, which most likely came from western Tibet and/or Central Asia, also makes its first appearance at this time. Finally, if the distinctive spinach-green colored amulet from a Period 3B burial is confirmed to be nephrite jade then there is a very good possibility that the stone used to make it came from the Kohat District, NWFP.

Harappa Phase – Period 3C (2200 to 1900 BC)

By the latter part of the urban phase – Period 3C, Harappans were acquiring 22 different rock and mineral varieties (Figure 13.5). The Haraza District, NWFP was once again the primary source for steatite. Small amounts were also being brought from deposits

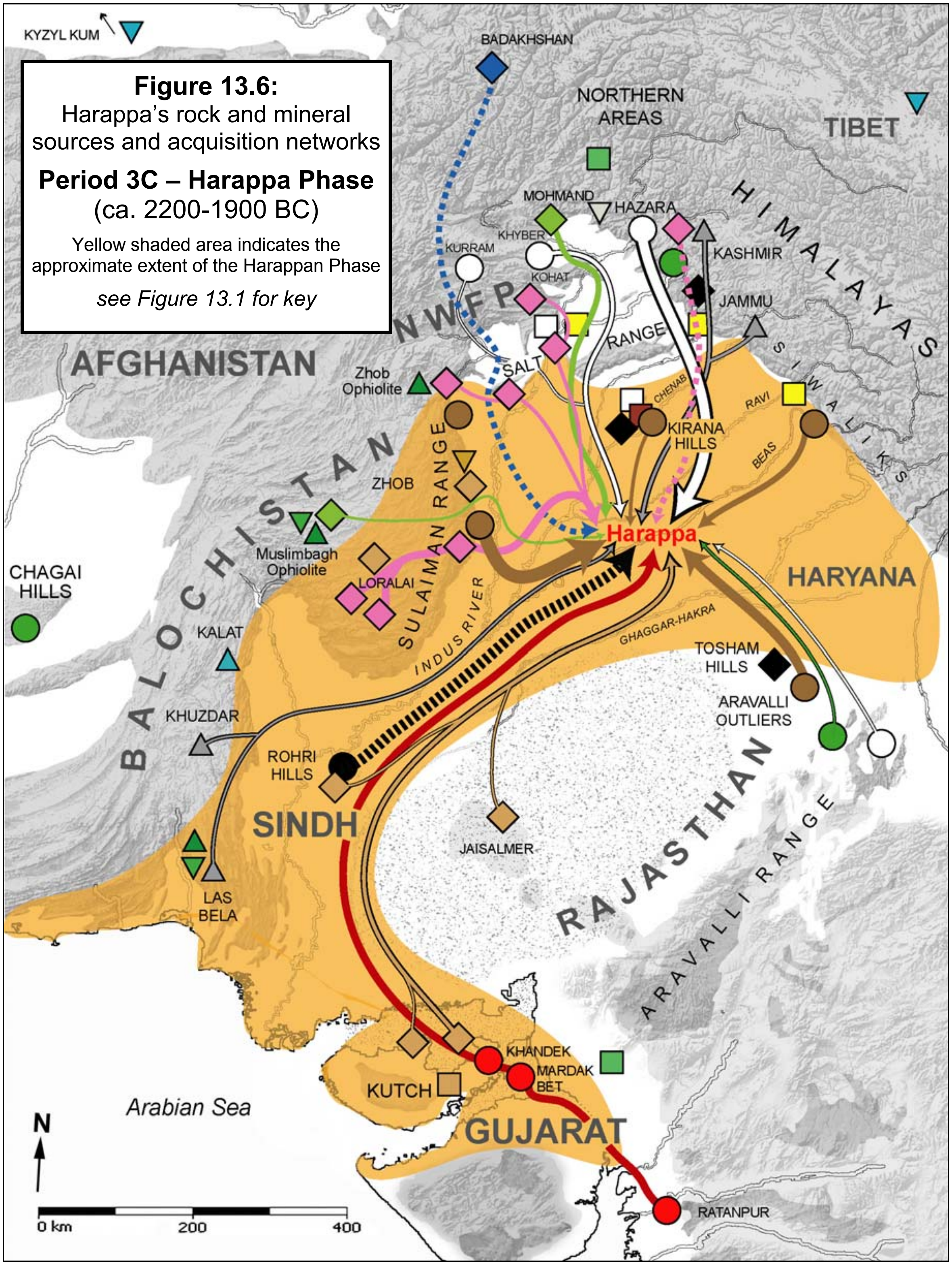


Figure 13.6:
Harappa's rock and mineral sources and acquisition networks

Period 3C – Harappa Phase
(ca. 2200-1900 BC)

Yellow shaded area indicates the approximate extent of the Harappan Phase

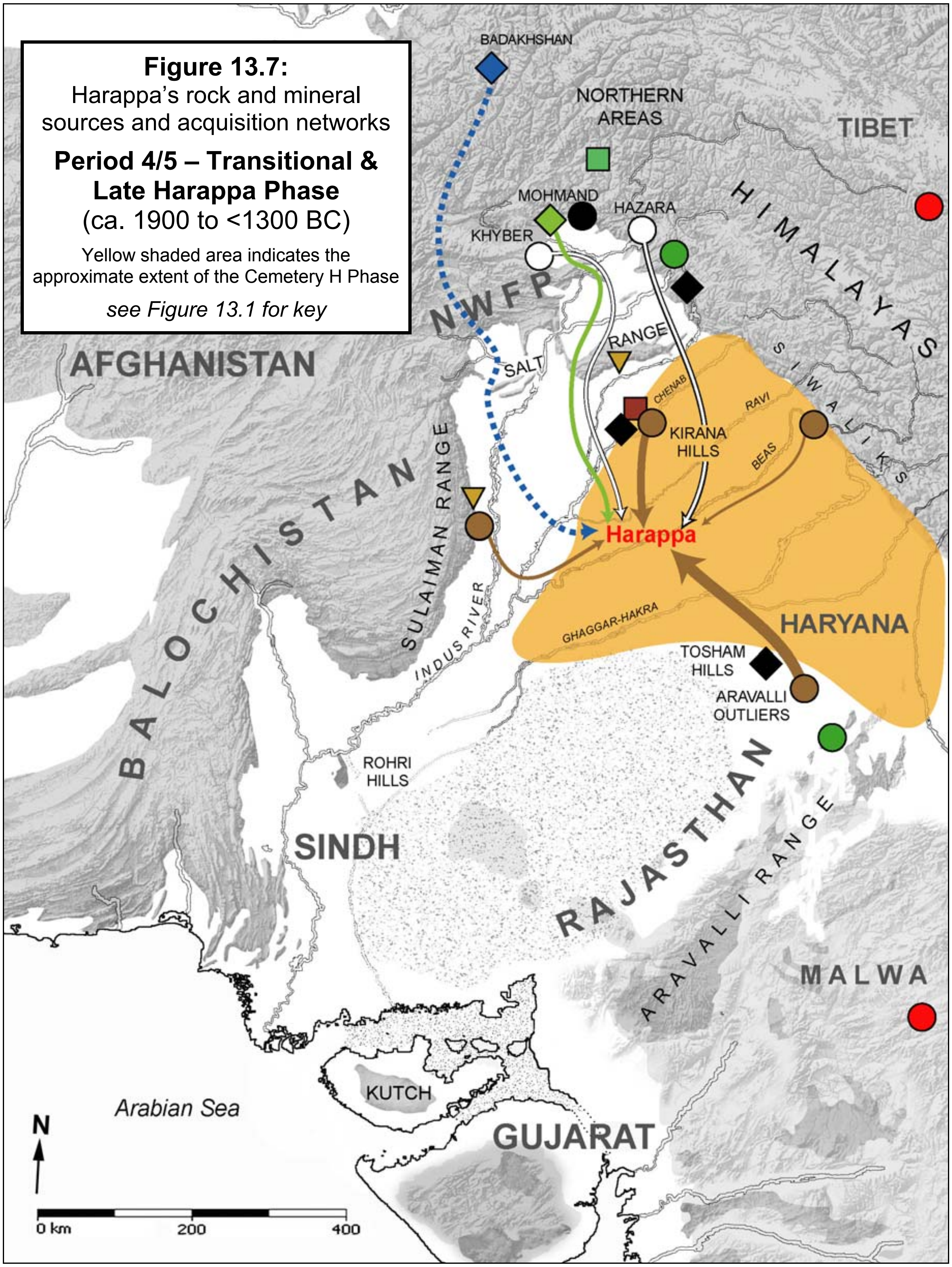
see Figure 13.1 for key

in the Khyber and Kurram agencies and the northern Aravalli Range but, for the first time, not from Jammu. Although Pab sandstone from the Sulaiman Range remained the most acquired type of grindingstone during Period 3C, its use decreased somewhat while there were increases in the amounts of raw material brought from the three other major sources. Vesuvianite-grossular was now obtained from sources in two regions – the Mohmand Agency and the southern Zhob District (Muslimbagh ophiolite) of Balochistan. Alabaster was derived from sources in the western Salt Range (along with Mari "Diamonds"), Kohat, multiple sources across the Loralai / Sulaiman Range area of northern Balochistan and, perhaps, Jammu and Kashmir. Harappans were acquiring lead from deposits in Jammu and Kashmir as well as from sources in the Las Bela and Khuzdar districts of southern Balochistan. Various types of limestone were obtained from northern Kutch, the Rohri Hills, the Jaisalmer area of Rajasthan and, probably, the Loralai area of Balochistan. Agate was being acquired from at least three sources across Gujarat – Khandek, Mardak Bet and, now, Ratanpur in the southern part of the state. Finally, a malachite fragment from this period appears to be related to the copper deposits of the northern Aravalli Range.

Although no artifacts were analyzed, most chert used during Period 3C was probably still acquired from the Rohri Hills. Of the new materials in the assemblage, prehnite likely came from the Las Bela or Muslimbagh ophiolites, fluorite from the Kalat District of Balochistan, mica from the Northern Areas and fossil foramina from the Sulaiman Range.

Transitional and Late Harappa Phase – Periods 4 & 5 (ca. 1900 to <1300 BC)

Only 11 rock and mineral varieties were recovered during excavations of the poorly preserved transitional and Late Harappa Phase levels – periods 4/5 (Figure 13.6). They do,


Figure 13.7:
Harappa's rock and mineral sources and acquisition networks
Period 4/5 – Transitional & Late Harappa Phase
(ca. 1900 to <1300 BC)
Yellow shaded area indicates the approximate extent of the Cemetery H Phase
see Figure 13.1 for key
BADAKHSHAN
NORTHERN AREAS
TIBET
MOHMAND
HAZARA
KHYBER
HIMALAYAS
NWFP
SALT RANGE
SIWALIKS
AFGHANISTAN
CHENAB
RAVI
BEAS
KIRANA HILLS
SULAIMAN RANGE
BALOCHISTAN
Harappa
INDUS RIVER
GHAGGAR-HAKRA
HARYANA
TOSHAM HILLS
ARAVALLI OUTLIERS
ROHRI HILLS
SINDH
RAJASTHAN
ARAVALLI RANGE
MALWA
KUTCH
Arabian Sea
GUJARAT
N
0 km
200
400

however, indicate that northern interaction networks persisted into Harappa's late/post-urban phase. Steatite was being acquired from the Hazara District and the Khyber Agency; vesuvianite-grossular was brought from the Mohmand Agency; and lapis lazuli from northern Afghanistan evidently remained obtainable. No analyses of agate or chert from periods 4/5 levels were conducted so it is impossible to say whether or not those materials were still being brought from Gujarat and Sindh (respectively). Both, however, could have come from regions to the north. Agate sources, although remote, do exist in the western Himalayas and there are indications from prior periods (2 & 3B) that chert from the Mohmand Agency was sometimes brought to the site. On the other hand, agate sources to the southeast, in the Malwa Plateau region, might been more accessible during this phase.

A strengthening of acquisition networks extending toward regions southeast of Harappa is indicated by the grindingstone assemblage of the Late Harappa Phase. Whereas Pab sandstone from the Sulaiman Range had dominated this material sub-assemblage throughout Period 3, fewer than 10% of the querns and mullers recovered from periods 4/5 levels are made from it. Delhi quartzite from the Aravalli Range outliers in southern Haryana had, for the first time, become the single most acquired type of grindingstone. The use of stone from the Kirana Hills was also up significantly over the preceding period.

Provenience data from other prehistoric sites – Seventh to third millennium BC

Steatite, chert, grindingstone, agate, vesuvianite-grossular, alabaster, lead and silver artifacts from around two dozen additional sites were geochemically analyzed or visually examined for this study. The resulting provenience data provide a valuable supplementary perspective (Figure 13.8) with which to contextualize and interpret the results from Harappa.

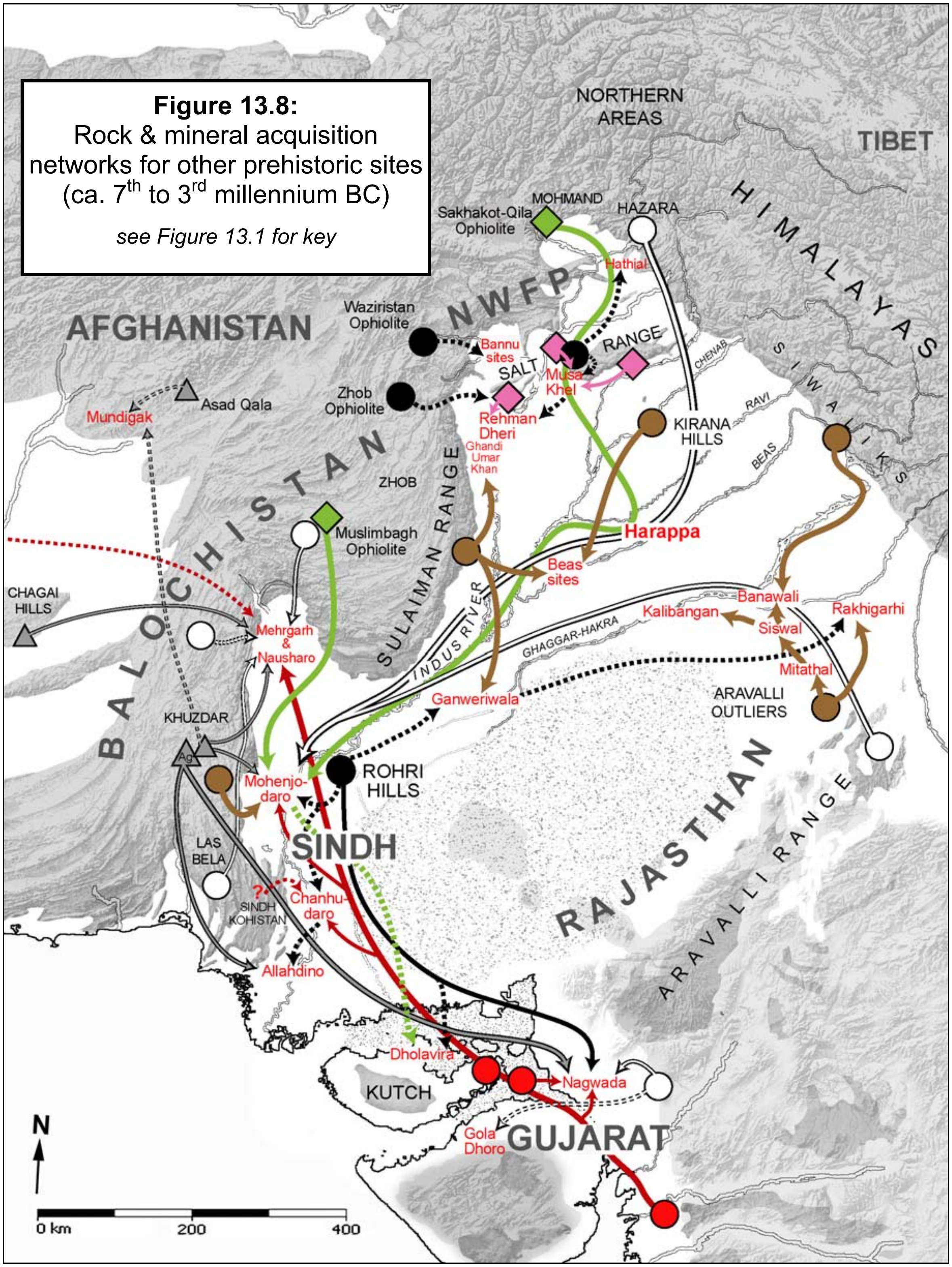


Figure 13.8:
Rock & mineral acquisition networks for other prehistoric sites (ca. 7th to 3rd millennium BC)

see Figure 13.1 for key

Analyses of steatite artifacts from six sites revealed both regional differences and similarities in the acquisition and use of that variety of stone. Residents of Neolithic to early Chalcolithic (ca. 7000 to 5000 BC) Mehrgarh acquired dolomitic and ultramafic steatite from sources in Balochistan. Those who later lived at the nearby Harappan town of Nausharo used ultramafic steatite from the Las Bela area of southern Balochistan, which was probably was not meant to be fired because it does not become white. The Harappans of Nagwada and Gola Dhoro in Gujarat also used ultramafic steatite, which they obtained from sources in the southern Aravallis. That stone (at least that used to fashion the seal analyzed from Gola Dhoro) apparently can be made white by heat-treating it. Most ultramafic steatite cannot be fired white, however, and it was probably for this reason (at least in part) that consumers at Mohenjo-daro exclusively used white-firing dolomitic steatite from two of the same source regions – the Hazara District, NWFP and the northern Aravalli Range, as residents of Harappa. Interestingly, steatite artifacts from the site of Tepe Hissar in Iran were also found to be of dolomitic origin.

Much was learned about patterns of chert acquisition in ancient South Asia from the examination of museum collections and site surface observations. Early Harappans living at settlements in Bannu Basin and Gomal Plain were using radiolarian chert/jasper from the nearby of Zhob and Waziristan ophiolites that, although often colorful, was clearly not the same as the purple chert/chalcedony used by their contemporaries at Harappa. On the other hand, the black-brown chert from periods 1 and 2 levels at Harappa, which was determined to have originated in the Sakesar Formation of the Salt Range, was apparently also acquired by Early Harappans at Rehman Dheri on the Gomal Plain; at Musa Khel on the southern

side of the Salt Range next to the source; and at Hathial on the northern margin of the Potwar Plateau. This regional black-brown chert distribution network evidently gave way (at least at Harappa) to the extra-regional distribution of tan-gray chert from the Rohri Hills of Sindh. The highly distinctive banded type of Rohri Hills chert was observed on the surface at and/or in excavation collections from each of the major Indus Civilization cities as well as smaller Harappan sites such as Allahdino and Chanhu-daro. One tan-gray chert sample from Harappan Phase levels at Nagwada in Gujarat was analyzed using INAA and found to be closely related to geologic samples from the Rohri Hills.

Querns and mullers from a dozen Early Harappan and Indus Civilization sites were examined (in collections and on site surfaces) using the same macroscopic criteria that were employed to assign geologic proveniences to grindingstone artifacts at Harappa. These observations, although limited, are beginning to reveal the extents of the various regional bulk stone transportation networks to which residents of Harappa had access. We see that, as it was moved west toward Harappa, Delhi quartzite from the Aravalli Range outliers was dispersed to sites like Mitathal, Siswal, Rakhigarhi, Banawali and Kalibangan. Like at Harappa, the gray sandstone observed at Banawali was probably brought from the Siwalik Foothills to the site via the waterways (in Banawali's case the Ghaggar River) draining that region. In the western Punjab, stone from the Kirana Hills was transported south beyond Harappa to sites along the lower reaches of the old Beas River bed. Pab sandstone from the Sulaiman Range was also observed at the Beas sites as well as to the south at Ganweriwala in Cholistan and to the north at Ghandi Umar Khan on the Gomal Plain. A great many (perhaps the majority) of the querns and mullers at Mohenjo-daro also

appear to be made from Pab sandstone. Those, however, were most likely acquired from the continuation of the Pab Formation in southern Balochistan.

Agate artifacts from Chalcolithic phase Mehrgarh and the Harappan Period sites of Nagwada, Chanhu-daro, Mohenjo-daro and Nausharo were compared to geologic samples from three agate sources in Gujarat and agate debris fragments from the proto-historic site of Shahr-i-Sokhta in Iran (which served as proxy samples for an Iranian agate source). As at Harappa, most of the artifacts resembled one of the Gujarat sources. A few from Mehrgarh and Nausharo did appear to be more closely related to the Shahr-i-Sokhta agates, which was not particularly surprising as those sites are located along the major transit way connecting the Indus Valley to highland Balochistan and, eventually, eastern Iran. Interestingly, two of the analyzed fragments from Chanhu-daro were also more closely related to the Iranian agates than to the Gujarati sources. Although they could be from Iran they may actually be from a poorly known agate occurrence in nearby Sindh Kohistan.

Vesuvianite-grossular fragments from Mohenjo-daro were determined to have originated in the same two source areas from which beadmakers at Harappa acquired that stone – the Sakhakot-Qila ophiolite in the Mohmand Agency and Muslimbagh ophiolite in northern Balochistan. Vesuvianite-grossular acquisition networks may have extended south to Dholavira, where artifacts made from the stone have been tentatively identified.

Alabaster fragments from the Kot Dijian / Late Kot Dijian Phase sites of Rehman Dehri and Musa Khel were found, not surprisingly, to have been derived from sources in the nearby Salt Range. Both sites were, quite possibly, places where this variety of stone and other resources from the region (such as black-brown Sakesar chert) were gathered

before being transported to Harappa. An alabaster vessel fragment from Mohenjo-daro could not be attributed to occurrences in the Salt Range or to any of the other sources examined. That item *may* represent an import from outside of the Greater Indus region.

A piece of galena from Mohenjo-daro was found to be isotopically analogous to lead deposits in the Khuzdar District, Balochistan. Lead residue in a small bottle recovered from that site could not be attributed to any of the sources examined in this study, however. Khuzdar lead was also being the acquired by the residents of late Neolithic Mehrgarh and nearby Harappa Phase Nausharo. A few galena fragments from Mehrgarh appear to be from a source to the west, perhaps in the Chagai Hills region. There are indications that peoples at Chalcolithic Mundigak in southern Afghanistan also used Khuzdar lead. They likely obtained some galena from nearby Asad Qala as well, although it is difficult to know with certainty until that and other lead deposits in Afghanistan are isotopically assayed.

Silver artifacts from four sites were assayed and compared to isotopic data from argentiferous lead deposits in the Greater Indus region and Iran. Nine of ten silver items from the Harappa Phase Allahdino jewelry hoard were found to be isotopically analogous to argentiferous lead occurring in the Khuzdar District, Balochistan. A silver ring fragment from Early Harappan levels at Nagwada in Gujarat was likewise found have likely been derived from that source. All silver artifacts analyzed from Mohenjo-daro, as well as one from Allahdino, could not be confidently assigned to any of the sources to which they were compared. These items *may* represent imports from outside of the Greater Indus region. Although the lead in a silver ring from Mundigak is analogous to a deposit in northern Pakistan (Chitral), it is more likely to have come from an unassayed source in Afghanistan.

Addressing the three lines of inquiry

Informed by the synchronic "pictures" of Harappan rock and mineral acquisition presented in the preceding section, the three lines of inquiry pursued in this dissertation are addressed one final time, beginning with: *With whom in the Greater Indus region or beyond were the residents of Harappa interacting, either directly or indirectly, when they acquired rock and mineral resources? What was the extent of those inter-regional relationships/resource acquisition networks during different periods in time?*

Rock and mineral artifact provenience determinations indicate that residents of Harappa "interacted" (recall the discussion of this term on pp. 47-48) with peoples in most every major region in and around the Indus Basin at one time or another. As those regions and the cultural phases associated with them are identified below, it may be helpful to refer back to the maps (Figure 2.6 A to D) and overviews (pp. 81-94) presented in Chapter 2.

In order to have acquired a substantial portion of the stone and metal items they possessed, Harappa's residents of all periods had to have been interacting with peoples that dwelled (either permanently or periodically) in regions to the north of their settlement. During periods 1 and 2, some of those northern peoples would have been other Early Harappans – other Ravi Phase peoples in the Rechna Doab; Tochi-Gomal Phase peoples in the Bannu Basin and Gomal Plain regions; and other Kot Dijians across all of those areas and up to the northern Potwar Plateau. Period 3 residents would have been interacting with "Late" Kot Dijians in those same areas as well other Harappans dwelling at least as far north as the Himalayan foothills, the southern flank of the Salt Range and the Gomal Plain. Beyond this the picture of interaction is less clear. Some degree of contact with Northern

Neolithic peoples almost certainly took place during both the Early Harappan and Harappan periods when site residents acquired stone and metal from the Kurram, Khyber, Mohmand, Malakand, Hazara, Jammu and western Kashmir regions. Although Northern Neolithic sites have not yet been discovered in the immediate vicinity of the sources identified in those areas, they are found in the nearby Swat and Kashmir valleys as well as the northern Potwar Plateau. Rock and mineral provenience determinations indicate that residents of Harappa continued to interact with the proto-historic peoples in many of those same areas during the Late Harappan (Cemetery H) Phase. Lapis lazuli artifacts unequivocally demonstrate a link with northern Afghanistan during all periods at Harappa. Who might have been present at that acquisition network's point of origin (no doubt for only a short portion of the year given its extremely high elevation) is unknown, however.

Rocks and minerals determined to have come from sources in the Sulaiman Range and northern Balochistan reflect interaction between residents of Harappa and their fellow Early Harappans (Kot Dijians) and Harappans in regions to the west. Grindingstones from the Kaliana Hills of southern Haryana demonstrate links with Early Harappan (Sothi-Siswal Phase), Harappan and Late Harappan (Cemetery H) peoples to the east. Stone and metal goods and resources from Sindh, Gujarat and southern Balochistan point to interaction with other Early Harappans (Hakra Phase peoples from Cholistan to northern Sindh during Period 1 and Kot Dijians dwelling as far south as Sindh Kohistan and, perhaps, the northern Gujarat region during Period 2) and Harappans in the southern reaches of the Greater Indus region. Lead artifacts from the Khuzdar region indicate some degree of interaction with Kulli Phase peoples of southern Balochistan during Period 3C at Harappa.

Evidence for interaction between residents of Harappa and the ancient peoples of Rajasthan exists but is limited. The handful of steatite artifacts (p. 379) and the single copper ore fragment (pp. 700-701) tentatively assigned to sources in the northern part of that state would seem to indicate that interaction with Malwa-Rajasthan Tradition peoples (Ganeshwar-Jodhpura Phase) took place during the Early Harappan and Harappan periods. Some limestone appears to have been brought to Harappa from the Jaisalmer area of Rajasthan during Period 3C. It is unknown, however, who inhabited that region at the time.

Before continuing it is important to again acknowledge that stone and metal artifact provenience data alone does not and can not capture the full scope of Harappan inter-regional relationships. Other lines of evidence – material (ceramic, shell, faunal, botanic), stylistic/iconographic and written (in contemporaneous Mesopotamia), indicate that Early Harappans and/or Harappans had connections with (and sometimes even dwelled in) distant regions from which it has not yet been demonstrated that rock and mineral goods or resources were being acquired. Some of these types of evidence are taken into account as I next consider the extent of inter-regional interaction/acquisition networks during different periods at Harappa and the degree to which they can be characterized as being external or internal to the successive cultural phases to which site residents belonged.

The presence of Rohri Hills chert and lapis lazuli in Period 1 levels shows that Ravi Phase residents of Harappa acquired stone from as far south as northern Sindh and as far north as northern Afghanistan. However, the marine shell also found in those levels (Kenoyer and Meadow 2000: 67) indicates that southern interaction networks for that phase actually extended to the Arabian Sea. Ravi Phase settlements are currently known only to

exist along middle and lower reaches of the Ravi River in the western Punjab. Therefore, apart from those materials attributable to the Kirana Hills, all rocks and minerals acquired by Harappans during Period 1 would have come to the site through external trade networks.

Shaffer's statement (1982: 192) that "with the exception of turquoise and lapis lazuli" all raw materials used to make the objects found at Indus Civilization sites occur "within the distribution area of the Harappan culture in the Greater Indus Valley," is true. It is mostly true of the preceding Kot Diji Phase as well. This does not necessarily mean, however, that all stone and metal goods and resources (save for turquoise and lapis lazuli) acquired by periods 2 and 3 residents of Harappa actually came from occurrences within the areas that peoples of their respective phases occupied. For example, minor instances of copper mineralization are found sporadically across the Greater Indus region. The nearest to Harappa (noted as #4 on Figure 4.13 in Chapter 4) is located in the Salt Range (Shah 1980: 99). However, that instance and most others like it (including the small occurrence in Waziristan assayed in Chapter 12) exhibit no evidence of ever having been worked and could not have yielded a substantial amount of metal even they had been. The closest sources that could have provided Harappans copper in the quantities they used all occur in areas external to the Indus Civilization (i.e. western Balochistan, northern Rajasthan and Oman). A somewhat similar situation exists for steatite. Although occurrences of the stone are fairly widespread, sources of raw material having the qualities that Harappans sought (workability and turning white when heat-treated) are few and relatively far a field.

In order for Kot Dijian and Harappan phase peoples to have acquired certain stone and metal resources in the quantities they used and with the qualities they sought, it would

have been necessary for them to have had access to sources outside of the areas (noted as the solid orange shaded areas on figures 13.3 through 13.6) across which they are presently known to have dwelled. That being said, most of the raw material sources that have been identified are located immediately adjacent to those areas. Some of them, such as the copper and steatite deposits of the northern Aravalli Range, lay in regions that were clearly occupied by non-Kot Dijian/Harappan peoples and so can be confidently characterized as external to those phases. However, the cultural associations of many others, especially those along the northern and western margins of the Greater Indus region, are much less clear. Most maps in this dissertation were made in a style (with lines or shaded areas demarcating the approximate extents of cultural phases) that creates the somewhat misleading impression that the cultures depicted on them were homogenous and well-bounded entities (see Smith 2005 for a discussion of this problem). In reality, the frontiers of the Kot Dijian and Harappan phases were probably not as well-defined as they appear to be on the maps, at least not in all areas. Some of the raw material sources that are located just beyond the northern and western-most known limits of those phases (such as the steatite deposits of Jammu or the vesuvianite-grossular source in Zhob) might have actually been internal to them. Even if they were not, most of the external rock and mineral acquisition networks that residents of Harappa were involved in do not seem to have extended very far beyond the regions across which peoples of the society they belonged to were primarily settled.

The latter finding is significant as there is a great deal of evidence demonstrating that Harappan interaction networks extended as far as Mesopotamia, the Arabian Peninsula, Iran and Central Asia (see discussion and citations on pp. 92-93). At present, however,

none of the artifacts analyzed for this study can be firmly attributed to geologic sources in any of those regions. A few lead artifacts and an alabaster fragment from Harappa, as well as a handful of items from other sites (an alabaster vessel fragment from Mohenjo-daro and some silver ornaments from that city and Allahdino), do not appear to be analogous to any analyzed occurrences of those materials in the Greater Indus region. The Pb isotope characteristics of six copper ore fragments from Harappa suggest that they may have from sources to the west of the Indus Valley or, perhaps, Oman. A few agate artifacts from Harappa, Nausharo and Chanhu-daro are chemically more analogous to agate used at the site of Shahr-i-Sokhta in eastern Iran than they are to samples collected from sources in Gujarat. The BMAC-like wig from Harappa does seem to be made from a type of steatite not typically used by Harappans. However, none of these data, although very intriguing, conclusively demonstrate that those materials were being acquired from sources in the Near East, Arabia, Iran or Central Asia. As far as the present study of stone and metal goods is concerned, imports from those regions remain as “invisible” (Crawford 1973) as ever.

This does not mean that such imports will always remain invisible. As I remarked above, some of the data are intriguing, in particular those for copper and silver artifacts. If Indus Civilization peoples were going to acquire rock and mineral goods from distant regions it would probably have been valuable metals such as those rather than materials like steatite or chert. The work I have done for this dissertation on copper and silver has been extremely limited in terms of both the number of artifacts and the potential sources analyzed. As the datasets for those materials grow in size and expand in scope, imports from sources outside of the Greater Indus region may become much more evident.

The full extent of rock and mineral acquisition networks during the Transitional and Late Harappan (Cemetery H) phases (periods 4 and 5) at Harappa is difficult to judge based on the limited assemblage that is available for study. It is, nonetheless, evident that materials like steatite and vesuvianite-grossular were still being acquired from sources to well to the north of the site. Although these sources were external to the primary region across which Cemetery H peoples are presently known to have lived, this status could change. Ceramic evidence suggests that those Late Harappans might have dwelled as far north as the Swat Valley (Stacul 1985). No agate artifacts from this period were analyzed and so it not possible is to confirm if that material acquisition network to Gujarat was still in place. However, the lack of marine shell from Cemetery H levels suggests that interaction with peoples that far south had probably ceased by this time (Kenoyer 2005).

In summary to this section: stone and metal artifact provenience data indicates that, at one time or another, residents of Harappa interacted with peoples in most every major region in and around the Indus Valley. Strong connections with groups in areas to the north evidently existed during all phases at the site. Interaction/acquisition networks with Haryana, Balochistan, Sindh and Gujarat varied depending on the period (these changes are discussed in more detail in the next section). Limited and somewhat tenuous evidence exists for long-distance contacts between site residents and the ancient peoples of the Rajasthan region. Although Indus Civilization interaction networks are know to have extended as far as Iran, Mesopotamia, eastern Arabia and Central Asia, these connections are not, as of yet, clearly evident in terms of the geologic proveniences of stone or metal artifacts at Harappa. Although external rock and mineral acquisition networks can be said

to have always been a feature at Harappa, with the exception of during Period 1, most of those networks do not appear to have extended too far beyond the area across which peoples of the cultural phase its residents belonged to at the time were primarily settled.

We now turn to the second line of inquiry: *How did the patterns of inter-regional interaction/resource acquisition exhibited by residents of Harappa change over time?*

Ravi Phase residents of Harappa were involved in interaction/acquisition networks that extended north to the Badakhshan region of Afghanistan, south to the Arabian Sea coast, west to the frontier of Balochistan and east to the southern Haryana/northern Rajasthan region. Over the next two millennia, some of those networks intensified or were augmented. Others diminished in intensity or were abandoned entirely. Still others appear to have remained constant throughout Harappa's long prehistoric sequence. In many ways, the evident diachronic patterns of rock and mineral acquisition correspond well with the generally understood and accepted sequence of inter-regional interaction during the emergence, existence and decline of urban lifeways in the Greater Indus region. Some patterns, however, may require us to reassess the significance of certain regions and the peoples that dwelled in them to the urbanization process.

No major changes are, at present, evident in the overall pattern of rock and mineral acquisition at Harappa between the Ravi (Period 1) and Kot Diji (Period 2) phases. This is despite the fact that the geographic scope of the latter society was considerably more extensive than that of the former. The use of steatite from sources in regions to the north of the site may have intensified somewhat by Period 2. Also, the Kot Diji Phase is the first in which agate from Gujarat and alabaster from the Salt Range has been positively identified

at the site. Such patterns should be treated cautiously, however, as the sample from Period 1 levels is extremely limited (only two steatite fragments and no agate or alabaster artifacts from earlier Ravi Phase contexts were analyzed).

The most significant changes in raw material source usage at Harappa took place around the Kot Diji to Harappa Phase transition (Period 2 to Period 3A). At that time, the acquisition of various cherts from occurrences to the north of the site (black Sakesar chert from the Salt Range and purple-hued chert-chalcedony most likely from the Pir Panjal Traps of Jammu and Kashmir) seems to have completely (or nearly so) ceased and given way to the use of tan-gray chert from the Rohri Hills of Sindh to the south. Similarly, grindingstone acquisition networks shifted in emphasis from relatively nearby sources to the north of Harappa (Kirana Hills) toward more distant ones to the west (Sulaiman Range). Steatite from a source in southern Balochistan also appears at this time (Period 3A) and is perhaps indicative of a new Harappan presence (at Bakkar Buthi) in that region.

Acquisition networks toward the south, west and east intensified as the urban phase progressed. By Period 3C, limestone from Sindh, Balochistan, Kutch and, perhaps, the Jaisalmer region of far western Rajasthan was being brought to Harappa. Lead from southern Balochistan as well as vesuvianite-grossular and alabaster from sources in northern Balochistan were likewise being acquired by that time. Agates and, very likely, the "Ernestite" used for making drills to perforate them were being brought from Gujarat. The Kirana Hills to the north had been practically abandoned as a grindingstone source. Although most stone used for that purpose still came from the Sulaiman Range, sources in distant Haryana (Kaliana Hills) to the east were steadily growing in importance.

It is thought that, by Period 5, residents of Harappa had ceased to interact with other Late Harappan peoples in the southern reaches of the Greater Indus region (Kenoyer 2005). However, it is not currently possible to support or refute this hypothesis with provenience data. No examples of the two materials that would most likely provide information on the matter – chert and agate, were analyzed from the site's limited Late Harappan levels. There is evidence from the grindingstone sub-assemblage that may be indicative of what is seen (Possehl 1997b) as an eastward demographic movement of Cemetery H Phase peoples during that period. The use of Pab sandstone from sources to the west appears to have fallen precipitously over Period 3C. Most grindingstone used during periods 4/5 was being brought from the Kaliana Hills, which are located around 400 km southeast of Harappa.

In contrast to the interaction/acquisition networks between Harappa and the southern, western and eastern parts of the Greater Indus region, which intensified and/or diminished over time, those extending toward the northern reaches of present-day Pakistan, India and Afghanistan appear to have remained fairly constant throughout the site's entire prehistoric sequence. Steatite, which has been analyzed for every period and shown to have mainly come from northern sources, and lapis lazuli, which is present in every phase, are the best indicators of this. Although chert from the Salt Range stopped being acquired after Period 2, alabaster from those mountains continued to be exploited during Period 3. Provenience data indicates that lead, vesuvianite and, perhaps, even small amounts of tan-gray chert were also acquired from northern sources during the urban phase at Harappa. Lapis lazuli, vesuvianite and steatite from the north demonstrate that interaction with the peoples of that region continued uninterrupted into the late/post-urban phase.

The diachronic perspective adopted for this line of inquiry permitted several ancillary issues related to changes in the use and/or acquisition of stone and metal goods at Harappa to be examined. When the composition of the site's rock and mineral assemblage was compared from period to period, it became evident that even though the geographic scope the Harappans' society changed significantly over time, the basic suite of raw materials they used remained, more or less, the same. While there are some variations between assemblages of different phases, most can be attributed to the lower probability of recovering less abundant varieties in less extensively excavated levels (recall Figure 4.12 and the discussion on pp. 184-185). The likely exceptions are for vesuvianite-grossular, "Ernestite," and limestone. Each of these materials seems to have been primarily (or exclusively in the case of "Ernestite") acquired and used during the latter portion of the urban phase (ca. late Period 3B and Period 3C). The coincident appearance of the first two was quite probably related. Beadmakers at Harappa simply could not have perforated vesuvianite-grossular until "Ernestite" was discovered or its source otherwise became accessible. I consider the former to be more likely the case as the results of the agate provenience study (Chapter 8) indicate that raw materials from Gujarat – the region that "Ernestite" probably came from, were accessible to site craftsmen from at least Period 2 onwards. Limestone, on the other hand, was abundant in almost every part of the Greater Indus region to which Harappans of any period had access. I have argued (pp. 616-617) that its use to create bulk-sized, non-utilitarian objects during the late urban phase probably represents a new development in the way that Harappans (not just at Harappa but also at Mohenjo-daro) expressed social power through the consumption and display of stone.

The diachronic perspective revealed that acquisition patterns for certain utilitarian stone goods at Harappa change significantly over time. It is clear that the Ravi Phase founders of the settlement already participated in extensive (described above) inter-regional interaction networks. The stones they acquired through the more far reaching of them were ornamental materials like lapis lazuli and steatite. Utilitarian goods – namely grindingstone and chert, were primarily obtained from the closest occurrences, which contained material of marginal quality. This remained the case during the subsequent Kot Diji Phase, although use of higher quality materials from more distant regions did increase somewhat. With the onset of the fully urban phase (Period 3), the closest sources entirely (or nearly so) ceased to be exploited. This trend toward the acquisition of higher quality utilitarian stone from remote occurrences was probably due, in part, to the expanding geographic scope of the Harappans' society as well as the development/improvement of technologies (wheeled carts and watercraft) necessary to transport goods in bulk sizes and quantities over long distances. With regard to chert from the Rohri Hills of Sindh, which appears to have not only been the primary type used by residents of Harappa during the Integration Era but also by Indus Civilization peoples across northwestern South Asia, the trend is probably also indicative of an utilitarian material becoming a widely used symbol of group identity and a key item of exchange in the extra-regional economy. Ratnagar suggested (2001a: 354) that the distribution of Rohri chert was a "process handled by the rulers" of Indus society. While I agree (with qualifications – see p. 754), Smith has shown (1999) that long-distance trade networks for "ordinary domestic goods" had, at times, flourished in premodern South Asia without a "centralized government to provide economic infrastructure" (ibid.: 110).

In summary to this section: when the composition of Harappa's rock and mineral artifact assemblage and the geologic proveniences of select items analyzed/examined from it are regarded diachronically, we see that the inter-regional acquisition/interaction and material usage patterns of its residents in some ways changed and in other ways remained steady over the period of time that urban lifeways emerged in northwestern South Asia. During Period 1, acquisition networks already extended to the limits of the Greater Indus region even though the cultural phase that site residents then belonged to was confined to the western Punjab Plain. The strongest connections, which were with regions to the north of the settlement, seem to have continued uninterrupted (although not unchanged) from this time through Period 5 (Late Harappa Phase). As the different regional Early Harappan phases coalesced into the multi-regional the Indus Civilization, the Harappans' acquisition networks toward the south, west and east intensified and, in areas like Balochistan, expanded. The most significant changes in raw material source usage occurred around the Kot Diji to Harappa Phase transition (ca. Period 2 to Period 3A). At that time, the primary chert acquisition network shifted from the north to the south and grindingstone acquisition patterns expanded beyond the nearest occurrences toward much more distant sources of higher quality stone. The basic suit of raw material types used at the site remained more or less the same from the Early Harappa through the Harappa Phase, however. It was not until late in the urban phase (ca. Period 3C) that site residents began to acquire (at least on a large scale) varieties of stone like vesuvianite-grossular, "Ernestite" and limestone. During the post-urban Late Harappa Phase, inter-regional acquisition networks extending toward the east intensified while those to the south and west diminished or ceased.

The third line and final of inquiry asked: *Did synchronic variations in the patterns of rock and mineral resource acquisition and use exist between groups of people living in different habitation areas at Harappa?*

Synchronic assessments of Harappa's rock and mineral artifacts assemblage revealed mainly similarities but also a few notable differences between its mounded areas. Few significant variations in the geologic proveniences of stone and metal artifacts from different mounds were observed. During periods 3B and 3C, the residents of mounds E/ET seem to have been the only Harappans utilizing alabaster from and "unknown" source, which I believe to likely be located somewhere in Jammu and Kashmir or the NWFP. Other than that, it would appear that, during all periods, Harappans living and working in different parts of the site had access to and were acquiring raw materials and/or finished goods derived from the same geologic sources. Slight variations in source proportions were sometimes evident between mound sub-assemblages, however. The inhabitants of mounds E and ET always seem to have used more Pab sandstone from the Sulaiman Range than their contemporaries dwelling on mounds AB and F. During Period 3C, the people of Mound F appear to have used at least twice as much Delhi quartzite from southern Haryana as those in other areas of Harappa. They also may have utilized steatite from northern Rajasthan more than other site residents during that same period. While this might indicate that Harappans dwelling in these parts of the site had stronger trade connections with the peoples of those distant regions, such patterns should be treated with caution. Many of the apparent variations could be due to recovery bias (see pp. 184-185) as fewer trenches were excavated on mounds AB and F as compared to mounds E and ET.

The synchronic distribution patterns of rock and mineral artifacts at Harappa suggest that, during each period, people dwelling/working within the site's four main walled areas (mounds AB, F, E and ET) were using (and presumably had more or less equal access to) the same basic suite of raw materials. Most variations, where they are evident, are likely due to the low probability of recovering less abundant material varieties on all mounds. The only genuine exceptions are for "Ernestite" and vesuvianite-grossular (see the argument presented in Appendix 9.9), which seem to have been mainly used on mounds E and ET during periods 3B and 3C. Without "Ernestite" Harappans could not have perforated a stone as hard as vesuvianite-grossular. Kenoyer has suggested (1997b: 272) that its acquisition and use was a "closely guarded trade secret."

Other than the two varieties of stone just discussed, there is little synchronic variation of material use (or provenience) within the rock and mineral assemblage that might indicate different groups, whose "centers of power" (Kenoyer 1997a: 69) were Harappa's walled mounds, controlled access to specific material types. Of course, a raw material, such as steatite from the Hazara source, might have first been acquired by the residents of one mound and then distributed to consumers on the others. However, such an activity, if it occurred, cannot be detected using the methods employed in this dissertation.

The few genuine synchronic variations within Harappa's rock and mineral assemblage are very informative, particularly with regard to the relationship between the adjoining mounds E and ET. In addition to being the primary locations where "Ernestite" and vesuvianite-grossular were used, the two mounds exhibit grindingstone acquisition patterns that are practically mirror-images of one another. The production/use of alabaster

bangles to seems to have been exclusive to these two areas as well. These patterns of material use and production suggest that the inhabitants mounds E and ET were closely related and lend support the view (Kenoyer 1998: 55) that latter was an outgrowth or "suburb" that grew from and was incorporated into the former during Period 3B.

Discussion

Now that all of the provenience determinations have been brought to bear on the three lines of inquiry, some implications of what has been learned can be discussed.

The development and nature of Harappan rock and mineral acquisition networks

As far back as the Neolithic Period at Mehrgarh (ca. 7000 BC), Indus Tradition peoples were obtaining ornaments made of materials from extremely remote sources. Eventually, peoples there and at other Early Harappan Period settlements in the Greater Indus region began acquiring those materials in raw form and transforming them into items would have served to enhance the wealth, status and power of those who owned and controlled them. From this, Raymond and Bridget Allchin observed (1982: 107), and others later concurred (Kenoyer 1998: 38; Possehl 1999: 680), that the "trade in luxury goods, often over long distances, had already been established for thousands of years before the beginning of Indus urbanism." The results of this study confirm that long-distance acquisition networks for prestige-related rock and mineral goods and resources were indeed already in existence at the time of Harappa's founding. Their establishment did not, for the most part, either immediately precede or accompany the incipient-urban (Kot Diji) or fully urban (Harappa) phases at that site. Instead there seems to have been a steady intensification and augmentation of existing inter-regional networks during the millennium

or so leading up to emergence of the Indus Civilization at around 2600 BC. Long-distance trade, therefore, should not be regarded as new (or even particularly uncommon) phenomenon that alone prompted the socio-political developments that led to urbanism in northwestern South Asia. Rather, long-distance trade networks were ancient and intrinsic features of Indus Tradition societies whose existence facilitated the urbanization of the region and which themselves underwent significant changes during that process.

One of the most significant changes was the trend toward the acquisition of two types of utilitarian stone – chert and grindingstone, through long-distance trade networks. Generally in pre-modern societies, goods of this nature tended to circulate in exchange networks that were much more localized as compared to those for prestige-related resources and products (Hirth 1992). Of course, at Harappa and at most other Harappan settlements located on plains of the Indus Valley proper, utilitarian stone acquisition networks were necessarily broad to begin with. In her model of the scales of trade in Early Historic Period India, Monica Smith defined (2002: 140) *local trade* as an activity that could be undertaken in a single day by the fastest means of conveyance available. In this regard, there were no local trade networks for any kind of stone or metal at Harappa simply because there were no local sources. There was only *regional trade* (that taking place within the territory of a single cultural unit of a size that required those transporting something to spend a period of time away from their place of residence) and *long-distance trade* (which takes place across expanses that encompass multiple cultural phases and/or and ecological zones) (ibid.). The extent of grindingstone and chert acquisition networks, even though broad to begin with, expanded significantly – from regional to long-distance,

as urban lifeways emerged at Harappa and in the Greater Indus region. I have argued that this was due, in part, to the development/improvement of the wheeled carts and watercraft needed to transport goods in bulk sizes and quantities. However, another important contributing factor would have been the expansion over time of the system of internal trade networks through which residents of Harappa acquired stone.

Rock and mineral artifacts deriving from external sources – i.e., those located outside of the geographic area encompassed by settlements of the cultural phase to which residents of Harappa belonged, have been recovered from every chronological period and sub-period at the site. It can be stated, therefore, that external trade was continuous feature of Indus society, at least at Harappa itself. It was most pronounced during Period 1 when, as far as we presently know, Ravi Phase peoples were settled only in the western Punjab. However, from that time through the Harappa Phase, the system of internal acquisition networks to which Harappa's residents had access steadily expanded as the geographic scope of the society that they were a part of became larger and sources previously accessible only through external networks were encompassed into it. During Period 2, that system stretched from the Potwar Plateau to Sindh Kohistan. By Period 3, site residents could have acquired rocks and minerals from Haryana and large parts of Balochistan and Gujarat through internal trade networks. Although there would have been instances where entirely new internal networks were established as Early Harappan and/or Harappan peoples moved into new areas, the development process is best characterized as expansion through integration. That is, the vast internal system of the Indus Civilization was largely built upon various existing regional systems that were joined during the Integration Era.

Significantly, all but a few of the identified and probable rock and mineral sources that appear to have been external to the Indus system during the Integration Era are located in regions that were immediately adjacent to it. Moreover, the situation along those "peripheries" is often far from clear. Many of the sources lying just beyond the area where Harappan sites are found might well have been within the Indus system (recall the discussion on pp. 733-734). Whatever the case actually was, the results of this study indicate that, as far as rocks and minerals are concerned, the vast majority of external trade that residents of Harappa were engaged in involved interaction with peoples along the highland margins of the Greater Indus region. It is, of course, well-documented that Indus Civilization peoples had contacts with and sometimes even dwelled in regions far beyond this (see pp. 92-93). However, like Shaffer (1982: 200) and Chakrabarti (1990: 169), I found little evidence to support the views of researchers (Asthana 1978; Possehl 1990; Ratnagar 2004) who feel that long-distance trade with the ancient peoples of western Asia, in particular Mesopotamia, "may have played a significant role in … the development of Indus urbanization" (Possehl 1990: 276-277). It is true that the artifacts analyzed in this dissertation were not compared to any sources in western Asia and that there were a small number that could not be firmly attributed occurrences in the Greater Indus region. Nevertheless, at this point I have to concur with Lahiri's assessment (1990: 441) that while at times "there may have been raw materials involved in the long-distance trade between the Indus Valley, the Persian Gulf, Iran and Mesopotamia there is no reason to argue that Harappa or any other site of the Indus Civilization were in any way solely or even significantly dependent on such raw materials." Harappans would have found multiple

occurrences of practically every rock and mineral resource they required in abundance within or directly adjacent to the Greater Indus region.

Although I interpret the evidence presented in this dissertation as providing little support for the supposition that long-distance trade with western Asia significantly influenced the development of urban lifeways in the Greater Indus region, this does not diminish the fact that such trade indeed took place or the possibility that it may have been vitally important to *some* groups within Harappan society. That no firm evidence for those trade relationships was detected in this study of Harappa's rock and mineral artifact assemblage probably has a lot to do with the types of materials examined (see p. 735) as well as the geographic location of the site itself (this latter point is discussed in more detail below). However, when such evidence is detected at Harappa or at another Indus Civilization site (as I am confident it eventually will be) it must be put into perspective.

Kenoyer is correct in his assertion (1991a: 361) that "external trade was a critical factor to the internal controls that maintained the Indus structure." Controlling access to and managing the distribution of goods or raw materials from outside of the Greater Indus region would have been an important strategy for some elite groups in Harappan society who were competing (for wealth, power and prestige) with other groups that controlled different sources or kinds of essential resources. We may be certain that those Harappans whose relationships in Arabia, Iran or Mesopotamia enabled them to import goods or raw materials from those distant regions into the Indus system benefited greatly by doing so. It is possible that there where some groups (families, guilds, merchant castes, etc.) whose livelihoods were based largely or even entirely upon their network ties with western Asia.

However, those networks were only one aspect of what we are now beginning to realize was a vast, multi-regional and multi-tiered acquisition system that was primarily centered on raw materials that were usually available in multiple locations across northwestern South Asia. Ultimately, as Shaffer once remarked (1982: 191), "the evidence indicates that Harappan external trade with the West cannot be compared to that which existed between contemporary Mesopotamia and the Iranian Plateau or Persian Gulf, in terms of intensity, regularity or relative importance to cultural developments in these regions."

Competition and the control of essential resources

The extensive inter-regional trade system discussed above, in combination with the wide distribution and multiple occurrences of essential resources across northwestern South Asia, is argued (Kenoyer 2000: 89-90) to have been a critical stimulus for economic competition and socio-political development in the ancient Indus Valley. That is, this unique setting is seen as having presented early village communities and, eventually, different groups of city-dwellers with wide-ranging opportunities to vie with one another for wealth, power and social-standing by controlling raw material sources and/or access to material acquisition networks. It was, in essence, an optimal cultural and geographic environment for the promotion and maintenance of the social and political stratification characteristic of an urbanized society like the Indus Civilization.

In this dissertation, I have shed light on competition and the control of essential goods and resources at Harappa by conducting phase-by-phase synchronic assessments of the material variety and provenience composition the site's rock and mineral artifact assemblage. Although some striking differences that can be construed as evidence for

these behaviors were detected between different mounds, on the whole, the results were equivocal. Part of the trouble no doubt had to do with the sample. For all chronological phases, only a small, non-representative fraction of the site's mounds has been excavated. The methodology used is clearly better suited to a site where multiple large-scale horizontal excavations have taken place. Perhaps the biggest problem was the likelihood that even though many rock and mineral varieties might have been initially acquired by Harappans dwelling on one mound, they were subsequently dispersed to residents in other parts of the site, thus muting the inter-mound patterns of material control that I had hoped to detect.

The results of the site-wise synchronic assessments of material usage and provenience at Harappa have already been summarized above (pp. 743-745). In my estimation, the only usage patterns that are likely to be genuinely indicative of control of resources and competition between groups at the site are those for vesuvianite-grossular garnet and "Ernestite" – both of which are found mainly (≈ 90% of all artifacts in each variety) on mounds E and ET during periods 3B and 3C. I have examined these patterns at length (pp. 501-508 and Appendix 9.9) and explained how "Ernestite" was the only drilling material that Harappans possessed that could have been used to perforate a stone as hard as vesuvianite-grossular. I would argue that the distribution at the site of artifacts composed of these two materials is directly related to "Ernestite" being, as Kenoyer has suggested (1997b: 272), a "closely guarded [*controlled*] trade secret." Only those craftspeople on mounds E and ET who were working with drills made from this stone could have fashioned vibrant green vesuvianite-grossular beads. This would have translated into a *competitive* advantage for elites in that part of the site who controlled the production of status-defining

items. The distinctive Harappan-style long-barrel carnelian bead is also an item that only those who controlled access to "Ernestite" drills could have had manufactured. I have not undertaken a study of the locations at Harappa where such beads were made but if production was found to have been centered on mounds E and ET then that would provide excellent supporting evidence for the pattern of material control that I have argued existed.

The remaining material distribution patterns indicate that, by and large, people living in all parts of Harappa were using the same kinds of rocks and minerals. Similarly, when the provenience patterns for individual material types were examined synchronically, it became clear that, barring a few variations in source proportions that are of arguable meaning (see p. 734), all site residents had access to and were using materials derived from the same geologic occurrences. These patterns in no way rule out the possibility that there were certain groups at Harappa who had network ties that enabled them to alone control the importation of rocks and minerals from specific regions or sources. The problem (for me in terms of this study) is that restricting all imported materials to their own parts of the site would not, in most cases ("Ernestite" excepted), have been of much benefit to such groups. They could have garnered far more economic, social and politic power in the course of transferring (bartering, selling, gifting, providing as tribute or tax) their surplus resources to Harappans living in other areas of the site. Detecting group control of specific materials and material sources in the archaeological record of the site is, for this reason, problematic.

Even though intra-site exchanges have obscured inter-mound patterns, it is still possible to infer something about competition and the control of rock and mineral resources at Harappa by looking at the overall provenience results. Kenoyer argued (1995b: 221-

222) that the existence of multiple potential sources for most raw material varieties used by Indus Civilization peoples "must have presented a unique opportunity for competition between merchants and suppliers and a major problem for elites trying to control access to potentially high status materials." For each of the eight rock and mineral varieties from Harappa that were examined in detail, I was able to confirm that, during most periods, site residents utilized raw material from geologic occurrences located in two or more different regions. This likely indicates that multiple groups were involved in the supply of these material varieties. That is say, it seems unlikely that, for example, a group involved in transporting a material like Pab sandstone from sources over 200 km west of Harappa in the Sulaiman Range would be the very same group that supplied Delhi quartzite to the site from a source nearly 400 km to the east. Although the exact nature of any competition between various suppliers is difficult to speculate about at this time, it is now quite evident that consumers at Harappa would have had multiple choices for many or most of the raw materials that they wished to acquire. This situation would indeed have proved problematic for elites trying to control access to certain types of prestige-related rocks and minerals.

Finally, I interpret the dramatic shift in chert source utilization that occurs at the beginning of Period 3A as likely being the result of a group of Harappans monopolizing the market for that utilitarian stone. Recall (p. 248) that Ravi and Kot Diji Phase residents of Harappa were acquiring this material variety from no less than three different sources. By the Harappa Phase, however, chert from the Rohri Hills of Sindh was almost[1] exclusively used there and, apparently, at other Harappan settlements throughout the Greater Indus

[1] There are indications that cherts from sources in regions other than the Rohri Hills were utilized to a very limited extent at Harappa (Chapter 5) and Mohenjo-Daro (Kenoyer 1984a: 119) during the Harappan Period.

region. There were probably a variety of reasons why, even though many alternate sources would have been accessible to Indus Civilization peoples, this particular material type was utilized so extensively. To begin with, it was simply the best quality chert available. The large nodules of homogenous material occurring in the Rohri Hills permitted standardized long blades to be produced on an "extraordinary scale" (Biagi and Cremaschi 1991: 97). There were possibly aesthetic and/or symbolic reasons as well. The black-brown and colorful variegated cherts and jaspers that were popular materials for making stone tools in the Early Harappan Period might have fallen out favor. Something about the light-tan/gray homogenous and concentric banded types of Rohri Hills chert may have appealed to the Harappans' sense of purity and order. The highly distinct appearance and consistent density of the banded type are probably the main reasons why it was the most commonly used raw material for making Harappan-style standardized cubical weights. Weights with this appearance could not be replicated (i.e., faked) in any other type of stone.

Ratnagar has argued (2001a: 354) that the pan-regional distribution of Rohri Hills chert type reflects a "process handled by the rulers" of Indus society. Although I agree, I am not inclined to conceptualize those rulers as having been leaders of a single, politically unified extra-regional state (Ratnagar 1991: 169). Given the size and restricted geographic setting of the Rohri Hills within the Indus Valley, they could conceivably have been controlled by one community of Harappans based in northern Sindh that oversaw the extraction and monopolized the distribution of the valuable utilitarian resource there. I see that community as having been one of the many elite factions (merchants, landowners, ritual specialists, etc.) who, it is argued (Kenoyer 1994a: 77), were competing with one

another for political dominance in Indus cities. If one judges by the apparent ubiquity of this particular material type at settlements large and small across the Greater Indus region, then it is reasonable to conclude that these Harappan “chert barons” (who may have also had interests in other industries and areas) were exceptionally successful in that regard. Underlying their success were the factors that made their product widely desirable (discussed in the preceding paragraph), the technologies (wheeled carts and watercraft) that enabled them to transport it in large quantities over long distances and, importantly, the location of the Rohri Hills themselves in the geographic center of the Indus Basin along or near what would have been the principal north-south Harappan interaction/trade network.

Harappan inter-cultural relationships

One of the stated aims (p. 22) of this dissertation was to identify and evaluate the significance of Harappan inter-cultural relationships by studying the trade of essential raw materials. The peoples that residents of Harappa were interacting with, either directly or indirectly, when acquiring rock and mineral resources have now been identified (the results were summarized on pp. 730-733). During the Regionalization Era, some of those peoples were members of same cultural phase to which site residents belonged and some were part of different Early Harappan phases that would eventually come to be incorporated into the Indus Civilization during the Integration Era. There were others, however, which belonged to non-Early Harappan cultural phases. Later, during the Integration Era, site residents were interacting with fellow Harappans as well as various non-Indus Civilization peoples in highland areas adjacent to the Greater Indus region. In this section, I discuss the significance of these non-Early Harappan and non-Indus inter-cultural relationships.

Judging by rock and mineral acquisition patterns, the most important and enduring inter-cultural relationships for residents of Harappa were those with groups dwelling in regions north of the upper Indus Basin. Specifically, these would have been with Northern Neolithic Phase peoples – the highland agro-pastoralists found across the Swat, northern Potwar and Kashmir regions from the Early Harappan through the Harappan periods – and peoples of the "Late" Kot Diji Phase in the Potwar, Bannu and Gomal regions during the Harappan Period. With regard to the latter phase, Raymond Allchin advanced (1984: 53) three theories as to why it persisted in the north while Kot Dijian peoples in the south, including those at Harappa, were integrated into the Indus Civilization. The first was environmental. The intensive agriculture that Harappans practiced in the Indus Valley proper, Allchin argued, may not have been suited to the climate or irrigation regime of the north. Although this is not my area of expertise, it is my feeling that these were probably not inhibiting factors as agriculturalists had thrived in the Bannu and Gomal regions from the Sheri Khan Tarakai Phase (ca. 5^{th} and 4^{th} millennia BC) onwards. If Early Harappans could sustain settlements in the north then it is likely that Harappans could have also. Allchin's second theory was economic. The north, he hypothesized, may not have "offered raw materials which were in demand in the Indus heartland" (ibid.). This was plainly not the case as I have demonstrated repeatedly throughout this dissertation. In fact, we now know the opposite to have been true. The third theory was political. Allchin speculated that there may have been an "active opposition" by "Late" Kot Dijians in the north to Harappan control over the region (ibid.). This is conceivable, although it should be noted that there is no evidence whatsoever for violent confrontations between those two societies.

Although rock and mineral artifact provenience data demonstrate that residents of Harappa interacted with peoples to the north of the site that belonged to cultural phases other than their own, they provide little information as to the nature of those relationships. It may be helpful, therefore, to briefly consider the results in terms of the same three or four basic interaction scenarios that were discussed earlier (pp. 372-374) in regard to steatite acquisition networks.

One possible scenario is that Early Harappans (Ravi Phase peoples and Kot Dijians) and Harappans never directly encountered peoples of the northern highland regions where many of the identified rock and mineral sources are located. Instead, members of another cultural phase(s) acted as an intermediary between them. This scenario is unlikely to have been true during the Early Harappan Period. Firstly, there is no indication that any other cultural phases were then present in the north who might have acted as intermediaries. Secondly, Kot Dijian settlements are found up to the northern edge of the Potwar Plateau. Thus, during Period 2 at Harappa, site residents could conceivably have acquired raw materials from fellow (at that time) Kot Dijians who dwelled in the north and made forays directly (without intermediaries) into adjacent (for them) source areas occupied by Northern Neolithic peoples. During Period 3 at Harappa, however, the "Late" Kot Dijian peoples living along the northern periphery of the Greater Indus region may themselves have sometimes served as intermediaries between Northern Neolithic peoples and Harappans to the south. In fact, some of the Kot Dijian materials reported at Northern Neolithic sites might actually be from this time period. For example, among the local Neolithic materials at Ghalegay rock shelter in Swat, Stacul described (1987: 39-40)

ceramics comparable to those at "sites displaying the late Kot Dijian style" in levels that produced a calibrated radiocarbon date of 2180 BC (ca. early Period 3C at Harappa).

Another possibility is that Northern Neolithic and/or "Late" Kot Dijian peoples sometimes traveled southward to Harappan settlements on the Punjab Plain, carrying with them raw materials for trade that they obtained from sources in their home territories. This scenario is most applicable to peoples of the former cultural phase who, by the mid-to-late third millennium BC, were reportedly raising domesticated sheep, goat and cattle at highland settlements like Gufkral in the Kashmir Valley (Sharma 1983a, 1983b). The seasonal migration regimes of herders and their flocks are the foundation of the ancient and still continuing "symbiotic relationships" between highland and lowland peoples all along "western borderlands" of the Indus Valley (Fairservis 1975: 233; Possehl 1999: 14-15). Shaffer argued (1978: 153) that because their wide-ranging transhumant lifeways afforded them "knowledge of points of consumption, as well as possible sources of supply," those pastoralists would have been the primary procurers and conveyers of raw materials from prehistoric Balochistan. Northern Neolithic herders, like historical Himalayan pastoralists such as the Gaddis and Gujars (Drew 1875: 107-111), might have performed a similar role in the "northern borderlands" of the Greater Indus region. The vast stretches of grazing land that were available in the bar uplands of the western Punjab doabs (Possehl 1984) would certainly have been an impetus for them to migrate southward to that region during the winter months. The Northern Neolithic sites that Possehl reported (1999: 548) in the Thal Desert tract (the Indus-Jhelum doab) near Leiah might even be the remains of their seasonal camps. Still, no such sites have been identified anyway in the vicinity of Harappa

and no artifacts (ceramics, stone tools, etc) that would provide an unambiguous association with that cultural phase have even been recovered there.

A seemingly more likely scenario would be one involving Northern Neolithic and "Late" Kot Dijian peoples coming into contact with Harappans in the highland-lowland transition zone where those cultural phases met. Evidence for inter-cultural interaction between these phases at Early Harappan and Harappan settlements excavated along that zone is limited[1], however. That is to say, material culture belonging to non-Harappan phases is not as evident at them as it is at, for example, sites along the southern Indus frontier in Gujarat like Nagwada (Hedge et al. 1988) and Gola Dhoro (Bhan et al. 2004). Certainly nothing resembling an enclave of Northern Neolithic or "Late" Kot Diji Phase peoples dwelling at a Harappan settlement (or vice-versa) has ever been discovered along the northern highland-lowland transition zone. In some places, peoples of different phases do seem to have dwelled in close proximity to one another. For example, on the Gomal Plain, the small Harappan site of Hisham Dehri (Dani 1971: 31) is located just 500 meters north-northeast of the larger Kot Dijian site of Rehman Dehri. Two radiocarbon samples taken from sealed floor levels in latter site's third and final occupational phase (RHD III) provided calibrated dates of 2170 BC and 2090 BC (Thomas and Allchin 1971: 39-40), which indicates that it was occupied well into the Harappan Period. It is, therefore, highly likely that the "Late" Kot Dijians of Rehman Dehri and the Harappans of Hisham Dehri were contemporaries living within sight of one another[2]. Currently, we can only speculate

[1] A single burial at Ropar and some ceramics at Chandigarh (Ropar and Chandigarh are Harappan sites located in the extreme eastern part of the highland-lowland transition zone under discussion – see Figure 3.5) exhibit Northern Neolithic parallels (Possehl 1999: 552). A few Northern Neolithic ceramic forms continue in very limited numbers into mid-Kot Diji Phase levels (Period II) at Sarai Khola (Mughal 1972: 37).

[2] The same situation *may* have existed to the southwest at the sites of Maru I and Maru II (Khan et al. 2000).

about the nature of the relationship between the peoples of those settlements. However, there is little evidence to suggest that it was hostile[1]. Whatever the situation actually was, it is clear that while "Late" Kot Dijians on the Gomal Plain and elsewhere somehow resisted social integration with Indus Civilization peoples, this did not impede Harappan acquisition of raw materials from beyond the northern frontier of the Greater Indus region.

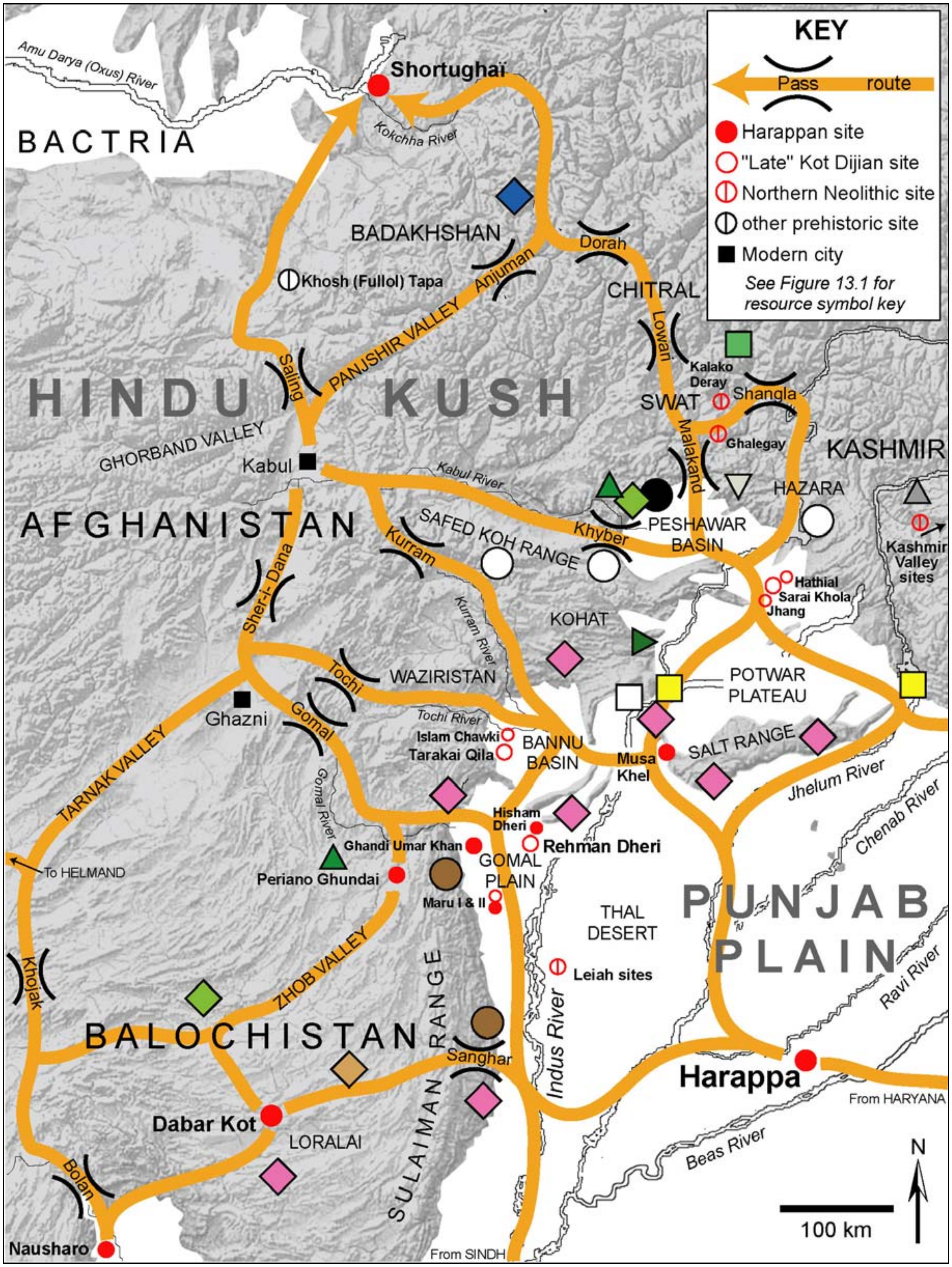
Harappans themselves may have sometimes traveled beyond the northern frontier and interacted directly with peoples dwelling in rock and mineral source areas. Of all the basic scenarios reviewed here, this is the one we can be most confident actually occurred. The reason is because of the existence of the Indus Civilization site of Shortughaï. Harappans obviously had to have made the journey to northern Afghanistan at least once in order to found that settlement. It is probably be safe to assume that they traveled there and returned multiple times. Figure 13.9 is a map depicting the major routes leading from the upper Indus Basin to Shortughaï. It is recognized that there are numerous other pathways that Harappans might have taken[2] and that just because a particular one (such as the Khyber Pass) is famous in the modern era does necessarily mean that it was important in the past. However, those depicted here became the best known and most utilized historically mainly because they were among the most expedient. Even owing for changing landforms in this tectonically active region, it is highly likely that they would have been during the prehistoric period as well. In addition to the possible routes, identified and probable

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[1] Bridget Allchin's theory (1982: 237) that Hisham Dehri was the camp of a "Harappan army" laying siege to Rehman Dehri does not hold up well under scrutiny – i.e., terracotta "cakes," which are found in abundance at Hisham Dheri, were probably not weapons (projectiles) and there is no other evidence for violent conflict. Xu's interpretation (1990) that Kot Dijians and Harappans had an "antagonistic" relationship is based largely on the existence of a "burnt" layer at the site of Kot Diji that may not have actually been the result of conflict.

[2] For instance, in addition to the primary Kurram and the Tochi river routes, there are 32 minor passes from the Bannu Basin through the Waziristan Hills alone (Thomas and Knox 1994: 93).

Figure 13.9: Majors routes from the upper Indus Basin to the Harappan site of Shortughaï



Harappan Period rock and mineral sources are plotted on the map along with pertinent Indus Civilization, “Late” Kot Dijian and Northern Neolithic sites.

In Appendix 13.1, I evaluate the different routes depicted on Figure 13.9 in detail. Although Indus Civilization peoples may have journeyed to Shortughaï along any of them, I have concluded that the evidence most favors a route that first passed through either the Potwar Plateau / Peshawar Valley regions or the Gomal Plain. That no Harappan sites (or non-Harappan sites with evidence Harappan contacts) have yet been discovered in the former regions does not greatly diminish this assertion as there are large parts of northern Pakistan that remain to be systematically surveyed. Three decades ago, Possehl remarked (1979: 545-546) upon the apparent paucity of Indus Civilization settlements in the western Punjab. Since then, surveys in that region (some of which remain incomplete) have revealed the existence of a number of such sites (recall discussion on pp. 76-77). Alternately, over two decades of intensive work by the Bannu Archaeological Project (Khan et al. 2002b) has failed to detect any Harappan presence in that region, which is one of the reasons why I consider it unlikely to have been an important pathway to Shortughaï. The results of this study suggests that there may be Harappan sites yet to be discovered across the Potwar Plateau and in the Peshawar Valley; probably in the large unsurveyed areas and/or beneath the numerous Historic Period settlements that exist in both regions.

Harappans journeying to Shortughaï by a route passing through the Potwar Plateau and Peshawar Valley would have encountered “Late” Kot Dijians and, probably (certainly if they were continuing north via the Swat Valley), Northern Neolithic Phase peoples too. Who they might have interacted with in regions beyond this is unclear. The cultural

landscape of late prehistoric northeastern Afghanistan is still largely *terra incognita*. What little evidence exists indicates that it was a region where peoples from distant lands dwelled alongside indigenous Chalcolithic phases (Lyonnet 1977, 1981). The fragmentary gold and silver vessels that were recovered from a hoard at Khosh (Fullol) Tapa and dated to ca. 2600-1700 BC had stylistic parallels linking them to both the Helmand region and Mesopotamia (Maxwell-Hyslop 1982; Tosi and Warwick 1972). Valuable resources, especially lapis lazuli but also precious metals, were no doubt what impelled peoples from those distant lands to make the arduous journey to northern Afghanistan. Future research may eventually show that this region, like eastern Arabia, was one of the places where Harappans closely intermingled with multiple cultures from across Middle Asia.

Although it is difficult, at present, to say much about the nature and dynamics of Harappan relationships with non-Indus Civilization peoples in the north, they were clearly integral to the development and maintenance of urban lifeways at Harappa and, by extension, in the Greater Indus region. That having been said, these were not the only inter-cultural relationships detected in this study of Harappa's rock and mineral assemblage. There are indications (reviewed on pp. 731-732) that site residents also interacted with non-Indus Civilization peoples dwelling in northern Rajasthan, southern Balochistan and southern Gujarat when acquiring certain varieties of stone and metal. That evidence, however, is far less abundant and far less varied than it is for the north. In some instances it is rather tenuous as well. Still, it would be a mistake to interpret it as suggesting that inter-cultural relationships with the non-Indus Civilization peoples of those regions were not also integral to the overall urbanization process in ancient northwestern

South Asia. They may have been less important to the residents of Harappa than others, but Harappa was only one settlement (albeit a major one) in the vast Indus realm. Its residents were well-situated geographically to have and benefit from relations with peoples in the north. It stands to reason that the inter-cultural relationships of Harappans dwelling in Indus Civilization cities located in other regions may have been very different indeed.

The primary rock and mineral resource catchment areas of Indus cities

One of the main accomplishments of this study has been to provide a new and detailed picture of the extent and direction of Harappa's rock and mineral catchment area. In this final discussion section, I use that understanding to model the catchment areas and acquisition/exchange patterns that might be associated with the other major Indus cities. I then briefly consider some of the undetected acquisition networks at Harappa from multi-regional perspective the model offers. I begin by reviewing Harappa's catchment area.

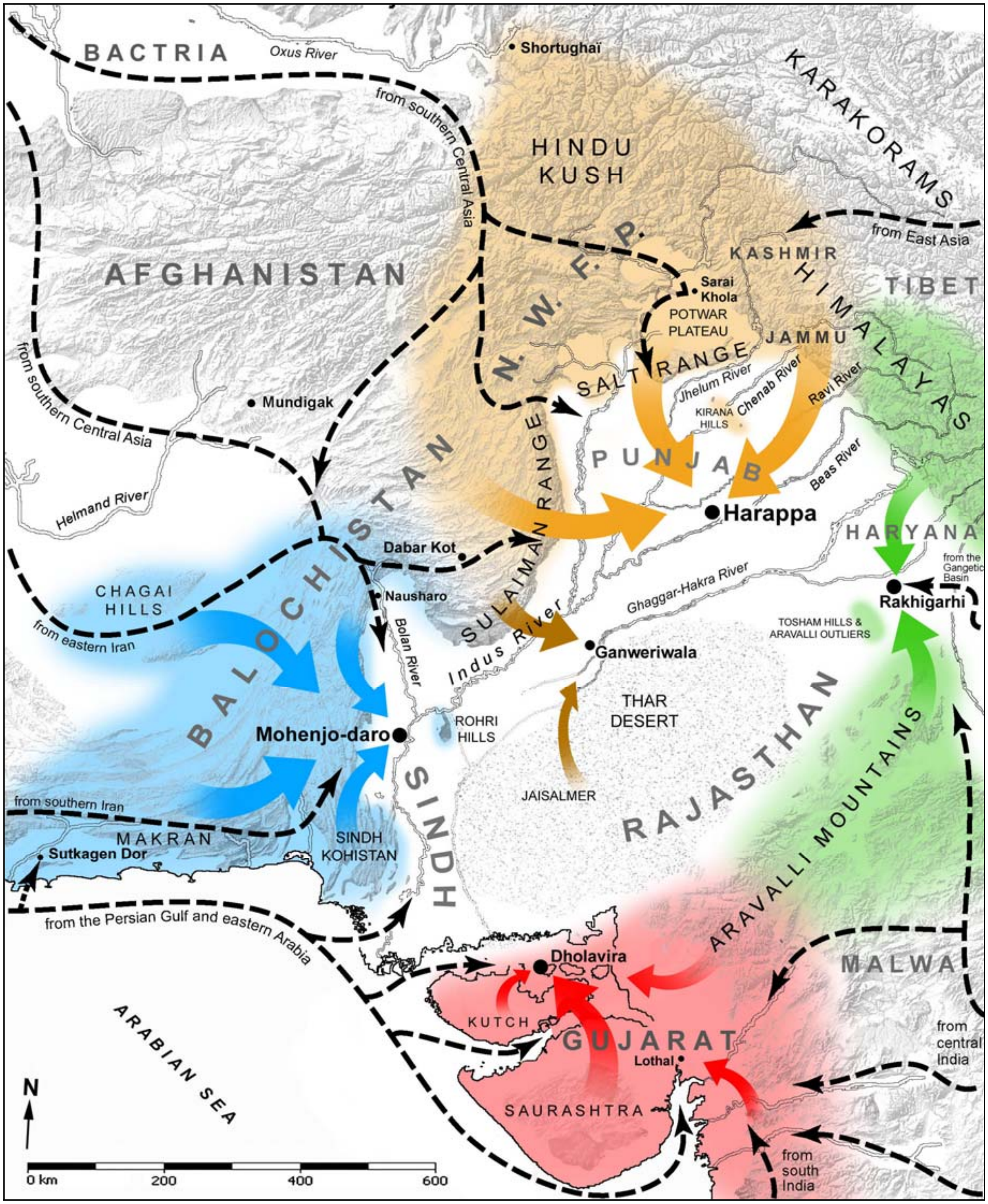
Harappa's primary rock and mineral catchment area

In Chapter 4, I discussed how, in simple terms of distance to the nearest potential sources of the rocks and minerals recovered at the site, Harappa is oriented toward the highlands west and north of the upper Indus Basin (recall pp. 186-187 and Figure 4.13). Of course, this is not particularly surprising if one just studies a good map. Geographically, Harappa is the Indus Civilization city located nearest to the Subcontinent's northwestern highlands and, thus, it was to be expected that many resources used at the site may come from that region. In fact, scholars like Fentress (1976), Ratnagar (1982) and Lahiri (1990) predicted this. In chapters five through twelve, I was able to confirm that a large portion of the stone and metal artifacts analyzed indeed were derived from sources within a broad,

semi-circular zone that began directly west of Harappa in the Sulaiman Range and extended through to the highlands north-northeast of the site in Jammu. There were some significant exceptions – such as chert from the Rohri Hills of Sindh and agate from Gujarat. Harappa's full rock and mineral catchment area was extra-regional and extended from at least northern Afghanistan to Gujarat, perhaps much farther. Even so, I would argue that it is appropriate to characterize it as being *primarily* oriented toward the northwestern highland zone described above. I have highlighted this zone (primary catchment area) on Figure 13.10 using orange-shaded terrain. Broad arrows represent the general movement of raw materials from the highlands toward Harappa (and not any one acquisition network).

Because of Harappa's location in the upper Indus Basin and its resident's now demonstrated acquisition/interaction links with the highland zone discussed above, I am not averse to informally labeling the site as the Indus Civilization's "gateway to the north." However, I expressly do not think it appropriate to characterize it using the formal geographic concept of "gateway settlement" (Burghardt 1971) as Ratnagar attempted to do in her article *The Location of Harappa* (1982). She hypothesized that the site was a lower-level tributary city on the Indus periphery that functioned as a "gateway" through which commodities from external sources flowed toward a primate city in the core, specifically, Mohenjo-daro. Because of this, it was thought that "transportation functions and facilities would outweigh the importance of manufacturing" at Harappa (Ratnagar 1982: 163). Ratnagar's hypothesis does not hold up under scrutiny but, to be fair, our understanding of settlement patterns in the Punjab, manufacturing activities at Harappa and the movement of goods and resources in the Greater Indus region has grown considerably since her article

Figure 13.10: Projected primary rock and mineral catchment areas for Indus urban centers



was published over a quarter-century ago. It is now understood that Harappa was not an isolated settlement on the northern Indus periphery (recall pp. 75-79) and that a huge and highly varied amount of craft manufacture took place there (Kenoyer and Miller 2007). Most importantly, we now know that, although the site's rock and mineral resource catchment area was largely oriented toward the northwestern highland zone, its residents had access to and were importing raw materials from all parts the Indus realm and, in some instances, beyond. Thus, Harappa was not merely a settlement through which commodities flowed from the hinterlands to the Indus core. It was a regional center of craft industries and trade as well as a nexus of inter-regional trade routes (Kenoyer 1995, Lahiri 1990).

Although Harappa was not a gateway city, there are indications that its residents were exporting some of the rocks and minerals they acquired from northern sources to consumers in other parts of the Indus realm. Most of the steatite fragments analyzed from Mohenjo-daro appear to be from the same northern occurrences (in the Hazara District, NWFP and the Kurram Agency, FATA) as the majority of those analyzed from Harappa. Likewise, most the vesuvianite-grossular fragments analyzed from Mohenjo-daro appear to be from the Sakhakot-Qila ophiolite on the northwest edge of the Peshawar Valley, just as were most from Harappa. While such provenience patterns obviously do not prove that these or any other raw materials from the northwest highland zone were transported along a particular route, given the primacy of Harappa in the upper Indus Basin and the orientation of its rock and mineral resource catchment area, it is not unreasonable to assume that they first came to that site before being traded elsewhere. Raw steatite may have been an especially valuable trade good for certain residents of Harappa. Recall (Chapter 7) that

even though occurrences of that stone are found in most every region surrounding the Indus Valley, those that would have yielded raw material with one of the main properties that Indus consumers desired – i.e., to become white when heat-treated, are mostly located in the dolomitic sequences of the northern Subcontinent. To represent this possibly important trade good from Harappa and its the northwest rock and mineral catchment zone, I have added the word "steatite" below the placemark for the site on Figure 13.10 and have drawn an orange arrow extending from it toward the lower Indus Basin and Mohenjo-daro.

Projected primary catchment areas for other Indus Civilization cities

I suggest that most of the other major Indus Civilization cities had rock and mineral catchment areas similar to Harappa's in that they were probably oriented toward adjacent highland regions and that certain high-value and/or unique material varieties found within each zone were traded to consumers throughout the Greater Indus region. Other researchers have made similar proposals (Asthana 1993; Fentress 1976; Lahiri 1992; Possehl 1993). However, the multi-regional model of acquisition and exchange that I offer here differs from past ones in several important ways: 1) Harappa's primary catchment area is now fairly well understood and is used to inform what those areas for the other Indus cities may have been like[1], 2) a limited number of geologic provenience determinations for artifacts from other sites have been produced (recall Figure 13.8) that provide a glimpse into acquisition patterns in other parts of the Greater Indus region and 3) I have approached the modeling of the primary catchment areas with an up-to-date perspective on the geology of northwestern South Asia that earlier researchers lacked (see pp. 98-99).

[1] For rock and mineral resources at least, it is now possible to move beyond projecting hinterlands for Indus cities by drawing circles around site locations on a map (as in Fentress 1976: Fig. 7 and Possehl 1993: Fig.2).

One of the most striking features of the Indus Civilization is the roughly equidistant distribution of its five largest cities – Mohenjo-daro, Harappa, Rakhigarhi, Dholavira and Ganweriwala, across the Greater Indus region (Mughal 1994a: 56). While many factors no doubt promoted the growth of those urban centers in the specific locations where they are found, in terms of providing Harappans access to stone and metal resources within and surrounding the Indus Basin, they could not have been more optimally situated, either individually or collectively. In addition to Harappa, I have projected primary rock and mineral catchment areas for Dholavira, Mohenjo-daro and Rakhigarhi on Figure 13.10 using red, blue and green (respectively) highlighted terrain. The omission of an area for Ganweriwala is explained below. As each provisional zone is introduced (starting with Dholavira and then moving northward), I make predictions regarding its extent and the major rock and mineral trade goods[1] that we might expect to see associated with it.

Dholavira's primary rock and mineral resource catchment area likely encompassed all of present-day Gujarat as well as adjacent highland areas in southern Rajasthan and eastern Madhya Pradesh. Ornamental microcrystalline silicates obtained were almost without a doubt the primary exports from the city and this zone. I have represented these on Figure 13.10 using a red arrow extending northward and the general term "agate," which I have confirmed (Chapter 8) was traded from sources in Gujarat to multiple Harappan sites in the Indus Valley proper. Other similar trade goods from this zone included yellow-brown banded limestone and, quite probably, "Ernestite" and amazonite.

[1] The materials that I have associated with Mohenjo-Daro (chert), Harappa (steatite), Rakhigarhi (metals), and Dholavira (agate), were almost certainly *not* the only ones being exported and they may not have even been the most important. They were simply the most obvious and/or probable exports. In addition to steatite, residents of Harappa were likely exporting materials such as vesuvianite-grossular and alabaster.

The primary rock and mineral resource catchment area for Mohenjo-daro would have probably encompassed the highland areas of Sindh and as well as large parts of southern and west-central Balochistan. Based on its distribution at Harappan sites across the Greater Indus region, it is no doubt safe to assume that chert from the Rohri Hills was one of the primary trade goods from this zone. I have represented this on Figure 13.10 using blue arrows extending toward the upper and lower Indus Basin regions. Metal resources – lead metal, raw lead ores and, possibly, silver from southern Balochistan and copper from the Chagai area, were also likely important trade goods.

Of all Harappan cities, Ganweriwala was the one most far removed from significant rock and mineral resources. Alluvial fans located about 125 km to the west of the site at the base of the southern Sulaiman Range were nearest stone sources of any kind. Basically, all that could have been acquired from them were siliciclastic sedimentary rocks for grindingstones. Alabaster and chert sources did exist around 100-150 km further westward. Also, some limestone from Harappa appears to have come from the low outcrops in the Jaisalmer area, 150 km to the south of Ganweriwala. Overall, however, the city's regional-level acquisition options were limited. To represent this, I have placed only brown arrows on Figure 13.10. Given the regional limitations and its location along what was certainly a major trade and communication route between the upper and lower Indus Basin regions, I predict that Ganweriwala's primary catchment area was necessity extra-regional in scope.

Rakhigarhi's primary rock and mineral catchment area likely encompassed material sources in the highlands both to its north and to its south. I predict that metals – gold and silver from the Himalayas and copper from the northern Aravalli Range, will be eventually

be discovered (or, in the case of copper, confirmed) to have been the major trade goods from that city/zone. These are represented on Figure 13.10 using green arrows. Steatite from sources in the northern Aravalli Range may have also been an important trade good as suggested by analyses of artifacts from Harappa and Mohenjo-daro.

The model presented here greatly simplifies what was assuredly a highly complex system. Nevertheless, it is a practical representation of what probably was the Indus rock and mineral acquisition system's multi-regional structure. The acquisition patterns evident in the assemblage at Harappa conform to the model; but that is to be expected as it was upon them that it is largely based. The question is: Will the patterns at the other Indus Civilization cities similarly conform to those predicted here? The limited work done on the matter so far suggests that they probably will. Based on my own preliminary observations of rock and mineral artifacts (both in-situ and in collections) from each of the other main Indus urban centers, I would provisionally suggest that Harappans at most of those cities were heavily exploiting raw materials from sources in the highland regions adjacent to them. Limited provenience analyses have already confirmed that some materials from each projected catchment zones were being exported to Harappa.

I wish to make it clear that the primary rock and mineral catchment areas for Indus Civilization cities that I have modeled here are economic interaction spheres and not political ones. Each zone, in fact, encompasses multiple distinct cultural phases. Harappans, "Late" Kot Dijians, Northern Neolithic peoples and, very likely, some poorly known Chalcolithic cultures in northern Afghanistan, were all included in Harappa's primary catchment area. Harappan and various non-Harappan cultural phases were

similarly encompassed in most of the other projected zones. These economic interaction spheres were joined with one another primarily through inter-regional trade among Indus Civilization peoples within the Indus Valley proper. We know from other lines of evidence that the multi-regional Indus system articulated, to varying degrees, with other interaction systems far to the west of the Greater Indus region. In this study, however, I have yet to positively detect evidence for such contacts at Harappa in the form of rock and mineral artifact provenience patterns. I have a theory, which I discuss next, as to why this may be.

A brief consideration of undetected acquisition patterns at Harappa

Before closing, it may be helpful to take advantage of the broad perspective the above model offers in order to briefly consider some of the acquisition patterns that were *not* detected in this study of Harappa's assemblage. Specifically, I refer to the lack of clear evidence for long-distance external trade with the ancient peoples of Mesopotamia, Iran and Arabia. Earlier I stated that I felt part the reason such evidence failed to be detected was because of the limited number of analyses involving copper and precious metal artifacts, which I believe were the most likely imports from those distant regions. Another part of the reason has to do with Harappa's position within the Greater Indus region.

I have placed black dashed lines and arrows on Figure 13.10 to represent the most likely routes by which finished goods or raw materials from areas outside of the Greater Indus region entered into the Indus Civilization's internal trade system. Note that Harappa, situated as it is in the upper Indus Basin and with its primary catchment area oriented to the northwest, is among the least optimally located urban centers in terms of access to the West Asian trade routes (only Rakhigarhi is in a poorer position). Mohenjo-daro and Dholavira,

on the other hand, are the two Indus urban centers whose primary catchments areas the land and sea routes from the west would have first encountered. Therefore, there is a far greater chance that evidence for the acquisition of rocks and minerals from sources in Arabia, Iran or Mesopotamia will be found in the assemblages of those cities. Western goods could, of course, have been then transported onwards to consumers at urban centers deep in the interior like Ganweriwala, Harappa and Rakhigarhi. However, Harappans at those cities may have had access to other, closer sources of the same material varieties. For instance, if we are talking about copper then the residents of Rakhigarhi might have had little need at all for imports because, as I have hypothesized, they had access to and were exporting that metal from sources within their own primary catchment area. The Pb isotope analyses I have conducted on the handful of copper ores from Harappa suggest that residents there were acquiring those ores from sources both to the west of the Indus Valley (*possibly* Oman) as well as from the northern Aravallis (within the Rakhigarhi zone). Harappans at Dholavira and Mohenjo-daro, having the best access to copper from western sources, might have been using it almost exclusively. When the rock and mineral assemblages of all Indus urban centers are eventually analyzed, we may see that the quantities of many imports (not just copper) at a city decreases or increases with its relative distance to the region where the Indus system articulated with external trade routes. This could explain, in part, why Arabian and West Asian goods have, thus far, failed to be detected at Harappa.

Chapter conclusion

The extensive geologic provenience analyses that were conducted for this dissertation on stone and metal artifacts from Harappa and others sites have helped to

generate a new and detailed understanding of resource acquisition patterns and inter-regional interaction during the initial manifestation of urbanized society in South Asia. Overall, most of the rock and mineral acquisition networks in which residents of Harappa were involved appear to have, over time, expanded, contracted and shifted in ways that correspond well with the generally understood and accepted cultural/chronological sequence of late-prehistoric northwestern South Asia. Provenience determinations demonstrate that, during one period or another, people living at the site interacted, either directly or indirectly, with peoples in most every other part of the Greater Indus region. The strongest, earliest and most enduring of the inter-regional relationships residents of Harappa appear to have had were with highland peoples dwelling in areas to the north of Indus Basin. External trade with these and other groups in highland areas directly adjacent to the Indus Valley was an important and continuous aspect of the socio-economic lives of Harappa's residents. Evidence in the site's rock and mineral assemblage for contacts with distant regions such as Arabia and Mesopotamia remains elusive, however.

There is still much work to be done. In the next chapter, I offer a few brief concluding remarks on the main accomplishments of this study and then some thoughts on the future directions that this research might take.

Chapter 14

Concluding remarks

Chapter 14 – Concluding remarks

In conclusion, I briefly highlight some of the accomplishments of this dissertation as well as discuss the future directions that this research might take.

Accomplishments and future directions

Although the acquisition and trade of rock and mineral resources by Indus Tradition peoples has been the subject of a great deal of scholarly attention over the years, prior to this study there were few serious attempts to systematically identify the actual geologic sources of stone and metal artifacts from sites in Pakistan or India. Perhaps the main accomplishment of this dissertation has, therefore, been the advancement of this type of provenience research in prehistoric South Asian archaeology. The large numbers of samples analyzed and the diverse range of rock and mineral varieties examined should provide a solid base for further studies. With regard to the specific materials examined thus far, let me briefly outline some of the future directions I intend to pursue.

Before this study, few scholars had paid much attention to grindingstones. Even fewer had given thought to their potential their sources. I examined all 2586 such artifacts recovered at Harappa and, by comparing them to geologic samples from the highlands in and around the upper Indus Basin, was able to identify the probable source formation of some 70% of them. In addition to continuing to source all newly recovered grindingstones at Harappa, it is my goal to examine those from as many contemporaneous sites in the upper Indus Basin region as possible. Through such studies, which can be done in-situ and non-destructively, I plan to trace in detail the networks through which these difficult-to-transport bulk items were moved hundreds of kilometers from their sources to Harappa.

A great deal has been learned in this study about chert at Harappa but much work remains to be done. I have identified two possible sources – one in the Salt Range and one in Kashmir, for the purple chert-chalcedony used during the site's early phases. Both will need to be field checked. It is now fairly certain that the black-brown chert used during the Early Harappan Period at Harappa came from the Salt Range's Sakesar Formation. The next step will be to analyze samples from across that extensive formation so as to identify the specific source(s) used. My analyses of tan-gray chert from Harappa and Nagwada confirm what many scholars have long assumed – that much of that material likely came from sources in the Rohri Hills of Sindh. There are, however, other tan-gray chert sources in Sindh, Balochistan and the NWFP that eventually will need to be sampled and analyzed.

The steatite provenience study that is the centerpiece of this dissertation is the largest ever conducted outside of the United States. Artifacts from Harappa and seven other sites were compared to geologic samples collected from sources in every major region surrounding the Indus Basin. It was found that Indus Tradition craftspeople mainly utilized steatite from dolomitic occurrences and, contrary to the predictions of many scholars, relatively little of it came from sources in Rajasthan. The majority of the artifacts analyzed from Harappa and Mohenjo-daro appear to have come from sources north of the Indus Basin. Knowing this, efforts will be made in the future to do more extensive sampling in the NWFP and Jammu and, whenever it becomes possible, to obtain samples from steatite occurrences in northeastern Afghanistan. Sampling excursions to central Balochistan and eastern Arabia will likely be necessary to locate the sources of (respectively) the black steatite used at Mehrgarh and the material to used make the broken seal at Gola Dhoro.

The agate provenience study presented in this dissertation was, to my knowledge, the first ever conducted using INAA. The results were outstanding. They confirmed that Indus Tradition peoples at sites like Harappa and several others in the Indus Valley were utilizing agate primarily from sources in Gujarat. However, it was determined that most of it probably came from occurrences in the eastern Kutch region rather than, as was widely thought, the more famous Ratanpur area deposits in the southeastern part of that state. There were also indications that agate from sources outside of Gujarat was sometimes used. As this study continues, the first step will be to focus on enlarging the geologic sample database to include sources in eastern Gujarat, Saurashtra and central Kutch. Minor but potentially important unsampled occurrences in Sindh, Balochistan and Kashmir will also need to be field checked. Eventually, when agate samples from sources (not proxy sources) in Iran, Afghanistan and Arabia are incorporated into the dataset, it should be possible to examine questions relating to the Harappan agate trade with western Asia in great detail.

Building upon work begun by Vidale and Bianchetti (1997), I was able to identify and document the full extent of vesuvianite-grossular use at Harappa. This rock, which in the past was misidentified as either jade or serpentine, is now known to have been the third most commonly used ornamental stone at the site (after steatite and agate-jasper). The provenience study conducted for this dissertation was the first ever involving this material. Using INAA, fragments from Harappa and Mohenjo-daro were compared to samples from the only known sources in Rajasthan, Balochistan and the NWFP and found to have originated in the latter two regions. The next step will be to similarly analyze examples of vesuvianite-grossular I have recently (July 2007) identified at the Indus city of Dholavira.

Strontium and sulfur isotope analyses of alabaster artifacts and source samples indicted that residents of Harappa were utilizing raw material from multiple occurrences in the Salt Range, the NWFP and northern Balochistan. A group of artifacts that had highly elevated Sr isotope values seem to have come from a source or sources not analyzed. Identifying that source(s), which there is a strong possibly might be located in the western Himalayas (Jammu and Kashmir and/or Hazara), will be a high priority in the future.

A large and varied set of limestone artifacts from Harappa was compared source samples using both INAA and a new technique involving mass spectrometry. Among the findings was that banded yellow-brown sandy limestone ringstones weighing in excess of 100 kg were probably being transported to Harappa from a source over 800 km to the south near Dholavira in northern Kutch. In the future, additional sampling and analysis will need to take place in order to, hopefully, better differentiate Kutch limestones from similar looking ones found in the Jaiselmer region. Also a third potential source of this distinctive material type in the Kirthar Range will need to be incorporated into the geologic dataset.

Pb isotope assays of lead, silver and/or copper artifacts from Harappa and other sites permitted many longstanding questions regarding the acquisition and trade of those metals to be addressed. Among the findings was that residents of Harappa were obtaining various lead ores from deposits in Jammu and Kashmir, Balochistan and at least one other, unknown source. Copper ores at Harappa seem to have come from northern Rajasthan as well as other sources that, although hard to pin down, probably lie west of the Indus Valley. The unknown lead source and vague proveniences of the copper artifacts highlight the need to conduct more extensive sampling and analysis of the potential sources of those metals.

In addition to a series of successful provenience studies, one thing I hope can be counted among the accomplishments of this dissertation is the infusion of a modicum of geologic reality into the general discussion of prehistoric rock and mineral acquisition and trade in the Greater Indus region. I strove to demonstrate that, among other things, it is not only important to be cognizant of where certain raw materials are found but also of where they are not and why. For example, although I was unable to actually visit the Chagai Hills of Balochistan, by looking closely at the published accounts of the geology there and critically looking at the environment in which the mineral lazurite forms, it was possible to, if not to actually disprove, at least to show that is tremendously unlikely that lapis lazuli could occur in that region. I also attempted to show that it was necessary to be aware that the quality of certain kinds of stone can vary considerably from source to source. Materials like chert, steatite and agate are fairly widespread but good quality chert, steatite and agate (i.e, that which Harappans would have found suitable for use) are much harder to come by. What's more, the properties that determine quality are not always readily apparent. Only through experimental heating of steatite samples from occurrences across the Greater Indus region did it become clear that the material at the majority of them would not become white when fired, which is a property Harappans sought. This explains why they were ignoring were so many accessible sources of seemingly excellent quality stone and focusing on a very specific few. Ultimately, what I tried to do in this dissertation was move beyond past studies that simply listed published locations of rock and mineral resources and assumed (without looking critically at either the original published reference or the material reported to occur) that ancient peoples were utilizing the nearest and/or most accessible sources.

Being given access to rock and mineral artifacts from a major archaeological site like Harappa was an honor and a privilege, not to mention a rare opportunity. Although it was impossible for me to analyze each of the 56,350 stone or metal objects recovered up to the point this project began, I endeavored to make full use of the assemblage by conducting a thorough inventory of it, categorizing all of the artifacts in a systematic manner by material variety, attaching a provisional spatial and temporal context to each one, quantifying the whole thing and then examining if and how it varied across time and space. I feel that this was an accomplishment on the order of any other achieved in this dissertation. Only by doing this was it revealed how, while the basic suite of rocks and minerals used at Harappa largely remained constant from period-to-period and from area-to-area, there were certain materials, notably vesuvianite-grossular and "Ernestite," which seem to have been utilized during specific periods and controlled by residents in certain parts of the city.

Much work remains to be done on artifacts from Harappa among the eight rock and mineral varieties that were the subjects of provenience analyses in this dissertation. The sub-assemblages for grindingstones and lead were examined in their entirety but more such artifacts are certain to be recovered. Roughly half of Harappa's limestone artifacts were analyzed but some of the minor varieties still need to be examined. Some 75 tan-gray chert artifacts from Period 3C must be analyzed just to achieve a 1% sample of that extensive sub-assemblage. The steatite provenience study is deficient with regard to samples from Period 1. Agate artifacts from all periods and parts of the site need analyzed. I would like to achieve a 10% sample of vesuvianite-grossular artifacts overall. Twelve additional alabaster artifacts need to be analyzed to achieve a 10% sample of that sub-assemblage.

There are a number of rock and mineral varieties at Harappa that are suitable subjects for large-scale geologic provenience analyses but which have not yet been studied in this way or have only been subjected to preliminary examinations. I am happy say the large and difficult task of identifying the sources of copper-alloy artifacts from Harappa is currently taking place under the direction of Dr. Mark Kenoyer at the University of Wisconsin-Madison. Among other the rock varieties that offer the greatest potential for future provenience studies is basalt, which I have already done limited work on in this dissertation. Serpentine, red and green jaspers, and amazonite are also materials that likely can be successfully sourced. However, I am most optimistic about future provenience studies involving Harappan gold, which was probably derived from numerous geologically distinct sources located around the Greater Indus region and beyond.

Finally, I hope in the future to expand my provenience research both beyond Harappa and the issues addressed in this dissertation. To some extent, this has already begun. Artifacts from a dozen other sites were analyzed here and materials from several others are currently being processed. I would very much like to replicate this study at other major Indus Civilization cities. Plans are being laid to make this a reality. However, some of the most interesting and important work in the future will be done at smaller sites, particularly those along the peripheries of the Indus Civilization where Harappans would have been directly interacting with non-Harappan peoples. I have shown in this dissertation that it was from such regions and, possibly, in this manner that Indus peoples acquired many of the rock and mineral resources that they used. At Harappa, it is only possible to detect and examine the end result of those inter-societal contacts. The best

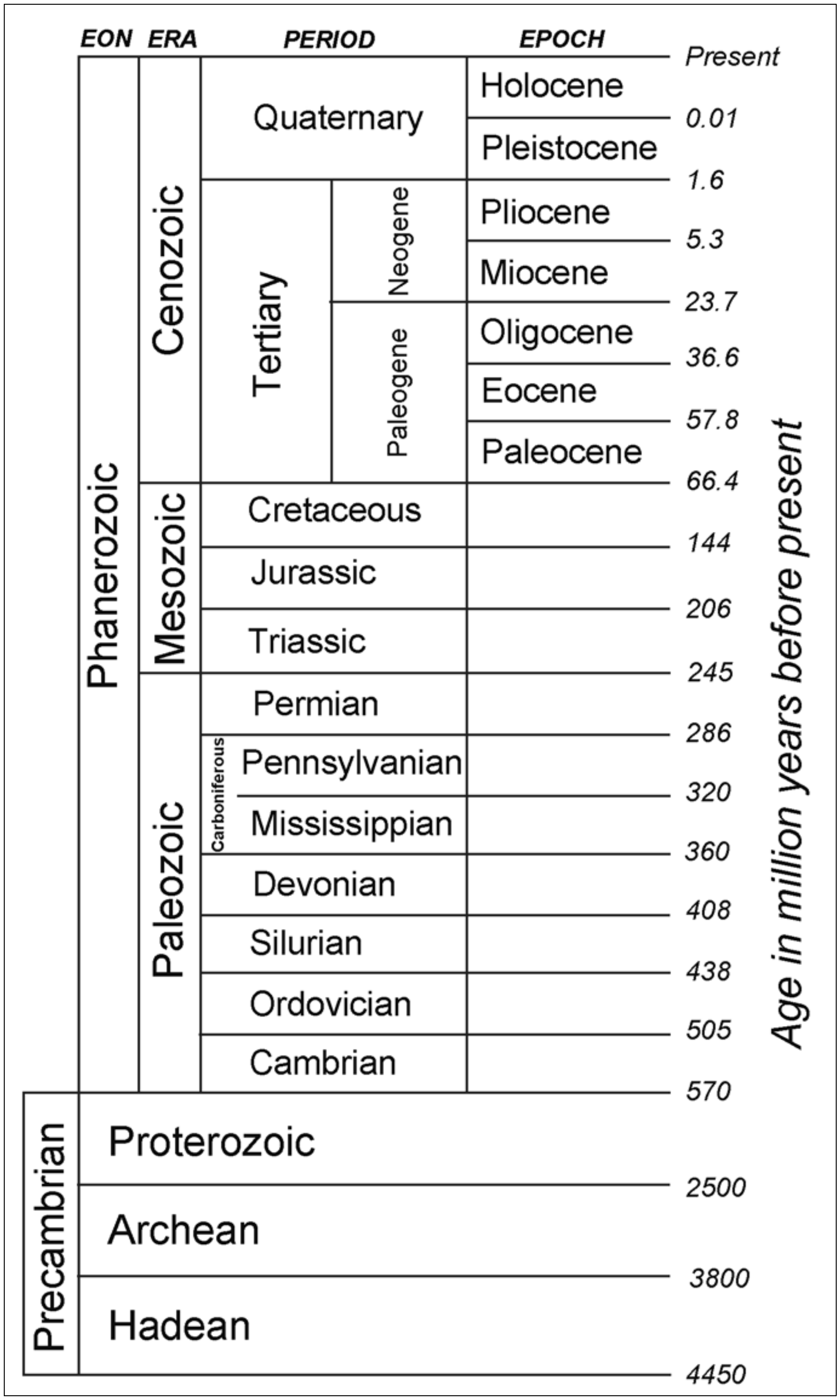
opportunity to find and study evidence of direct interaction with non-Harappan peoples is regions like Gujarat at sites like Gola Dhoro where peoples of a distinct indigenous cultural phase are documented to have existed alongside Harappans (Bhan et al. 2004). It is in such regions and at such sites that phenomena like trade diasporas and colonialism, or models of interaction like "world-systems" theory, can be and, have recently been (Chase 2007), examined and evaluated. I hope to one day examine those and related issues along the Indus Civilization's "northern borderlands" by studying the dynamics of rock and mineral acquisition and exchange in that region. However, before the types of questions that are now beginning to be addressed in Gujarat can be addressed in the north it will be necessary for a great deal of new data to be collected. This will required detailed, question-oriented excavation (or re-excavation) at Harappan sites in that region such as Ropar (Sharma 1982), Manda (Joshi and Bala 1982), Musa Khel (Dani 1971: 32) and Hisham Dheri (ibid.: 31).

In the meantime, there are untold number of stone and metal artifacts in collections from excavations and surveys of Early Harappan and Harappans sites across northwestern South Asia just waiting to be analyzed using the techniques demonstrated to be effective in this dissertation. The geologic datasets against which to compare such artifacts, although still being augmented, are now basically in place. In collaboration with scholars at institutions in India, Pakistan and elsewhere, I hope to embark on a broad-scale, long-term program aimed at identifying the sources of as many different varieties of rock and mineral artifacts from as many sites, large and small, as is possible. By doing so, we should be able to generate a picture of resources acquisition and inter-regional interaction in the Greater Indus region that is unprecedented in its detail and accuracy.

VOLUME TWO

Appendices

Appendix 2.1: Major divisions of geologic time.



Appendix 3.1: Mohs' Mineral Hardness scale

Hardness	***Mineral***
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase Feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

Appendix 4.1: X-ray diffraction analyses of Harappan rock and mineral artifacts - major and minor phases (*****minor phases determined by EMPA)

Artifact	**Description**	**Major Phase**	**Minor Phase(s) / [SG]**
H2000/9999-108	alabaster fragment	Gypsum	
H2000/9999-131	alabaster fragment	Gypsum	
H95/4943-8	copper mineral	Malachite	
H90/3126-1	copper mineral	Malachite	
H90/3022-98	copper mineral	Malachite	
H90/2070-12	copper mineral	Chalcocite	
H90/3008-13	copper mineral	Chalcocite	
H90/3008-14	copper mineral	Chalcocite	
H94/4999-529	copper mineral	Chalcocite	
H2000/2090-49	"Ernestite"	Mullite/Sillimanite	quartz, rutile, hematite, zircon*
H2000/3317-2	"Ernestite"	Mullite	cristobolite, titanohematite*, zircon*, phosphate*
H2000/3317-3	"Ernestite"	Mullite	cristobolite, titanohematite*, zircon* phosphate*
H2000/3317-4	"Ernestite"	Mullite/Sillimanite	quartz, rutile, hematite
H2000/9999-81	green pebble frag.	Quartz	albite*
H90/2076-6	green pebble frag.	Quartz	epidote*, albite*, sphene*
H90/3000-30	green pebble frag.	Quartz	epidote, rutile*
H90/3207-14	green pebble frag.	Quartz	felspar*, epidote*, albite*
H98/8499-351	green pebble frag.	Quartz	albite*
H2000/9999-126	green stone	Quartz	tremolite
H97/6977-7	green stone	Fluorite	
H96/6303-4	green stone	Prehnite	
H2000/9999-92	green stone	Quartz	
H95/4960-88	green stone	Quartz	
H2000/8990-1	green stone	Quartz	
H94/4999-213	green stone	Turquoise	
H2000/9999-87	green stone	Vesuvianite	[SG = 3.33]
H2000/9999-88	green stone	Vesuvianite	[SG = 3.29]
H2000/9999-89	green stone	Vesuvianite	[SG = 3.32]
H2000/9999-90	green stone	Vesuvianite	grossular / [SG = 3.32]
H2000/9999-93	green stone	Vesuvianite	[SG = 3.28]
H90/2076-7	green stone	Vesuvianite	[SG = 3.23]
H90/2080-1	green stone	Vesuvianite	grossular, clinochlore / [SG = 3.28]
H90/3000-31	green stone	Vesuvianite	[SG = 3.23]
H90/3011-153	green stone	Vesuvianite	clinochlore [SG = 3.29]

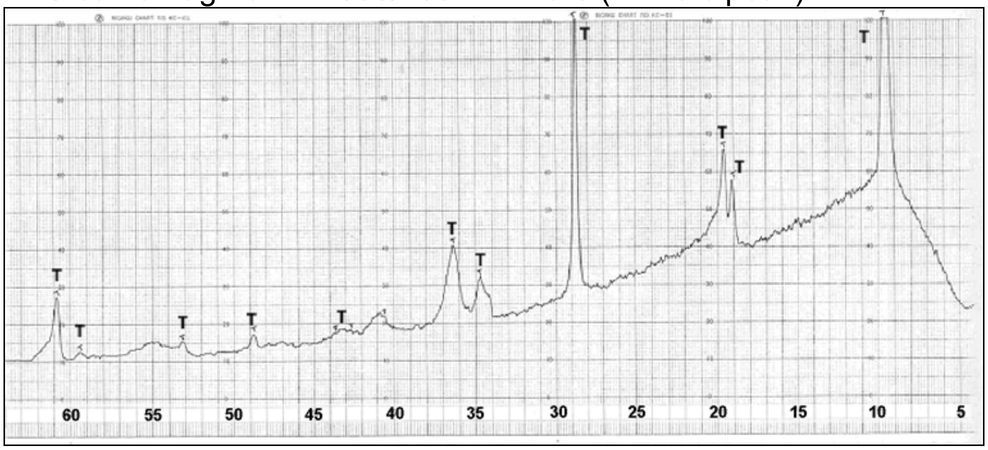
Appendix 4.1 (cont.): X-ray diffraction analyses of Harappan rock and mineral artifacts - major and minor phases (*minor phases determined by EMPA)

Artifact	Comments	Major Phase	Minor Phase(s) / [SG]
H90/3200-36	green stone	Vesuvianite	clinochlore / [SG = 3.19]
H90/3208-147	green stone	Vesuvianite	clinochlore / [SG = 3.29]
H90/3220-4	green stone	Vesuvianite	clinochlore / [SG = 3.31]
H94/4374-19	green stone	Vesuvianite	[SG = 3.27]
H94/4999-4	green stone	Vesuvianite	clinochlore / [SG = 3.28]
H94/4999-5	green stone	Vesuvianite	clinochlore / [SG = 3.27]
H95/4922-79	green stone	Vesuvianite	clinochlore / [SG = 3.29]
H95/4922-81	green stone	Vesuvianite	clinochlore / [SG = 3.32]
H95/5760-54	green stone	Vesuvianite	clinochlore / [SG = 3.23]
H95/5764-74	green stone	Vesuvianite	clinochlore / [SG = 3.26]
H96/6958-41	green stone	Vesuvianite	grossular, clinochlore / [SG = 3.32]
H98/8499-353	green stone	Vesuvianite	clinochlore* [SG = 3.32]
H94/5310-36	green stone	Clinochlore	vesuvianite / [SG = 2.98]
H96/7129-1	green stone	Clinochlore	vesuvianite / [SG = 3.16]
H2000/9999-91	green stone	Grossular	vesuvianite*, clinochlore / [SG = 3.45]
H94/5106-8	green stone	Grossular	vesuvianite / [SG = 3.45]
H94/4999-23	green stone	Lizardite	
H89/2006-159	green stone	Lizardite	
H2000/9999-77	Lapis Lazuli	Lazurite	calcite
H2000/9999-74	Lapis Lazuli	Lazurite	calcite
H90/3011-1	lead mineral	Galena	
H2000/2102-1726	lead mineral	Galena	stibnite
H2000/2226-111	lead mineral	Galena	stibnite
H2000/9999-73	lead mineral	Galena	stibnite
H90/8857-1	lead mineral	Cerrusite	anglesite
H99/8755-152	lead mineral	Cerrusite	anglesite
H2000/2139-141	lead mineral	Cerrusite	anglesite
H90/3193-6	lead mineral	Massicot	
H94/5530-13	limestone	Calcite	
H2000/9999-122	ochre fragment	Goethite	
H2000/2227-65	ochre fragment	Hematite	
H90/3073-34	ochre fragment	Hematite	
H94/4805-2	ochre fragment	Quartz	hematite
H95/5712-79	ochre fragment	Quartz	goethite

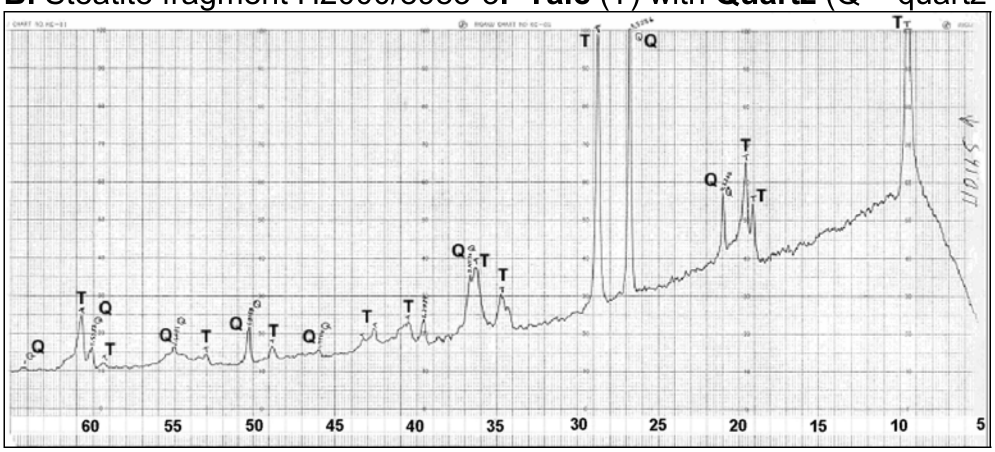
Appendix 4.1 (cont.): X-ray diffraction analyses of Harappan rock and mineral artifacts - major and minor phases (*minor phases determined by EMPA)			
Artifact	**Comments**	**Major Phase**	**Minor Phase(s)**
H2000/9999-107	selenite crystal	Gypsum	
H2000/9999-130	selenite crystal	Gypsum	
H2000/2084-1	steatite fragment	Talc	
H2000/2139-142	steatite fragment	Talc	dolomite
H2000/2222-2	steatite fragment	Talc	
H2000/2778-18	steatite fragment	Talc	
H2000/8983-3	steatite fragment	Talc	quartz
H2000/9448-3	steatite fragment	Talc	
H2000/9846-455	steatite fragment	Talc	
H2000/9999-96	steatite fragment	Talc	
H2000/9999-97	steatite fragment	Talc	dolomite
H2000/9999-98	steatite fragment	Talc	quartz
H95/5145-17	steatite fragment	Talc	
H95/5148-14	steatite fragment	Talc	dolomite
H95/5168-41	steatite fragment	Talc	
H95/5175-5	steatite fragment	Talc	
H95/5729-99	steatite fragment	Talc	dolomite
H95/5742-30	steatite fragment	Talc	
H95/5748-36	steatite fragment	Talc	
H95/5749-122	steatite fragment	Talc	
H95/5749-123	steatite fragment	Talc	quartz
H95/5759-26	steatite fragment	Talc	
H95/5803-25	steatite fragment	Talc	
H96/2115-52	steatite fragment	Talc	quartz
H96/5844-21	steatite fragment	Talc	
H96/6224-22	steatite fragment	Talc	
H96/6224-32	steatite fragment	Talc	
H96/7243-29	steatite fragment	Talc	
H98/8499-352	steatite fragment	Talc	
H98/8499-354	steatite fragment	Talc	
H98/8499-355	steatite fragment	Talc	dolomite
H2000/2110-77	tabular crystal	Calcite	
H96/6219-43	yellow-green stone	Sulfur	

Appendix 4.2: Representative XRD scans

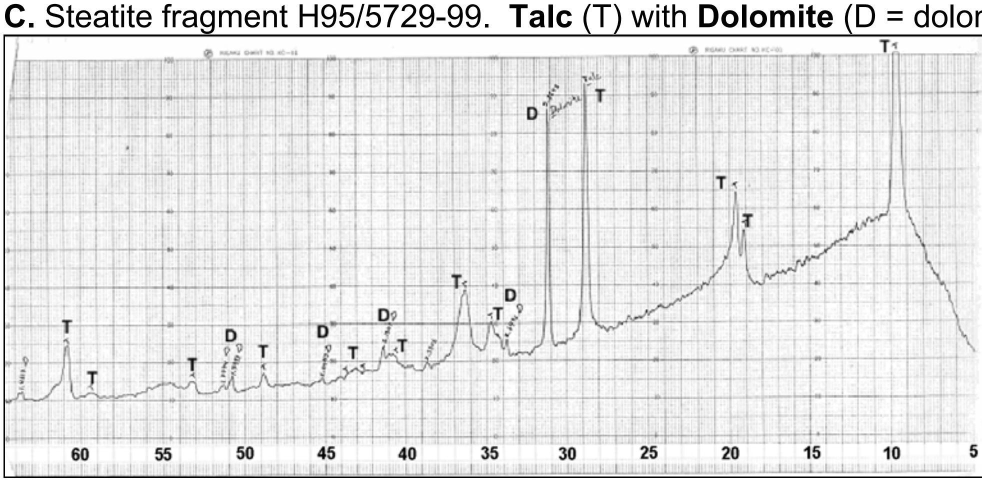
A. Steatite fragment H2000/2084-1**. Talc** (T = talc peak)



B. Steatite fragment H2000/8983-3**. Talc** (T) with **Quartz** (Q = quartz peak)

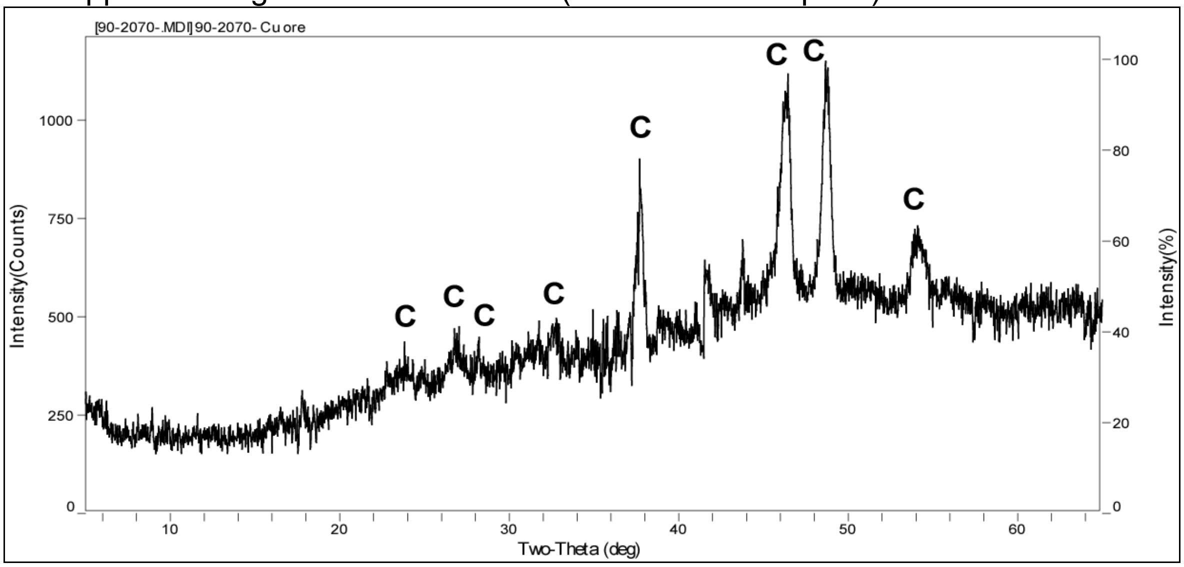


C. Steatite fragment H95/5729-99. **Talc** (T) with **Dolomite** (D = dolomite peak)

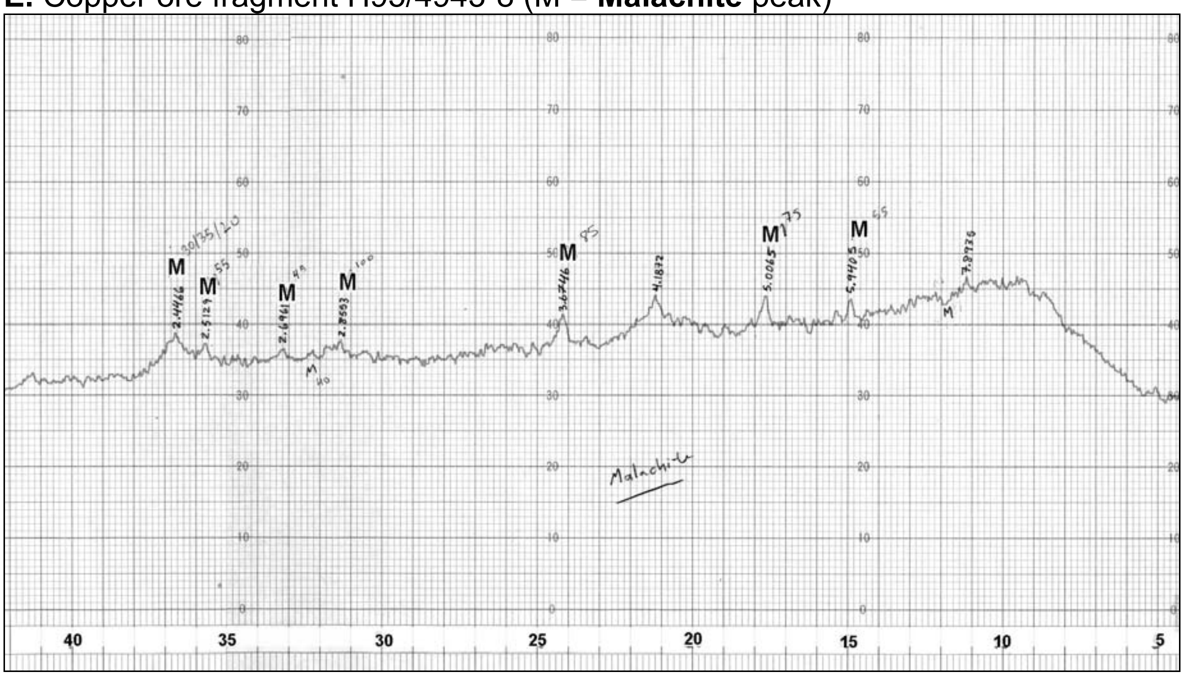


Appendix 4.2 (continued): Representative XRD scans

D. Copper ore fragment H90/2070-12. (C = **Chalcocite** peak).

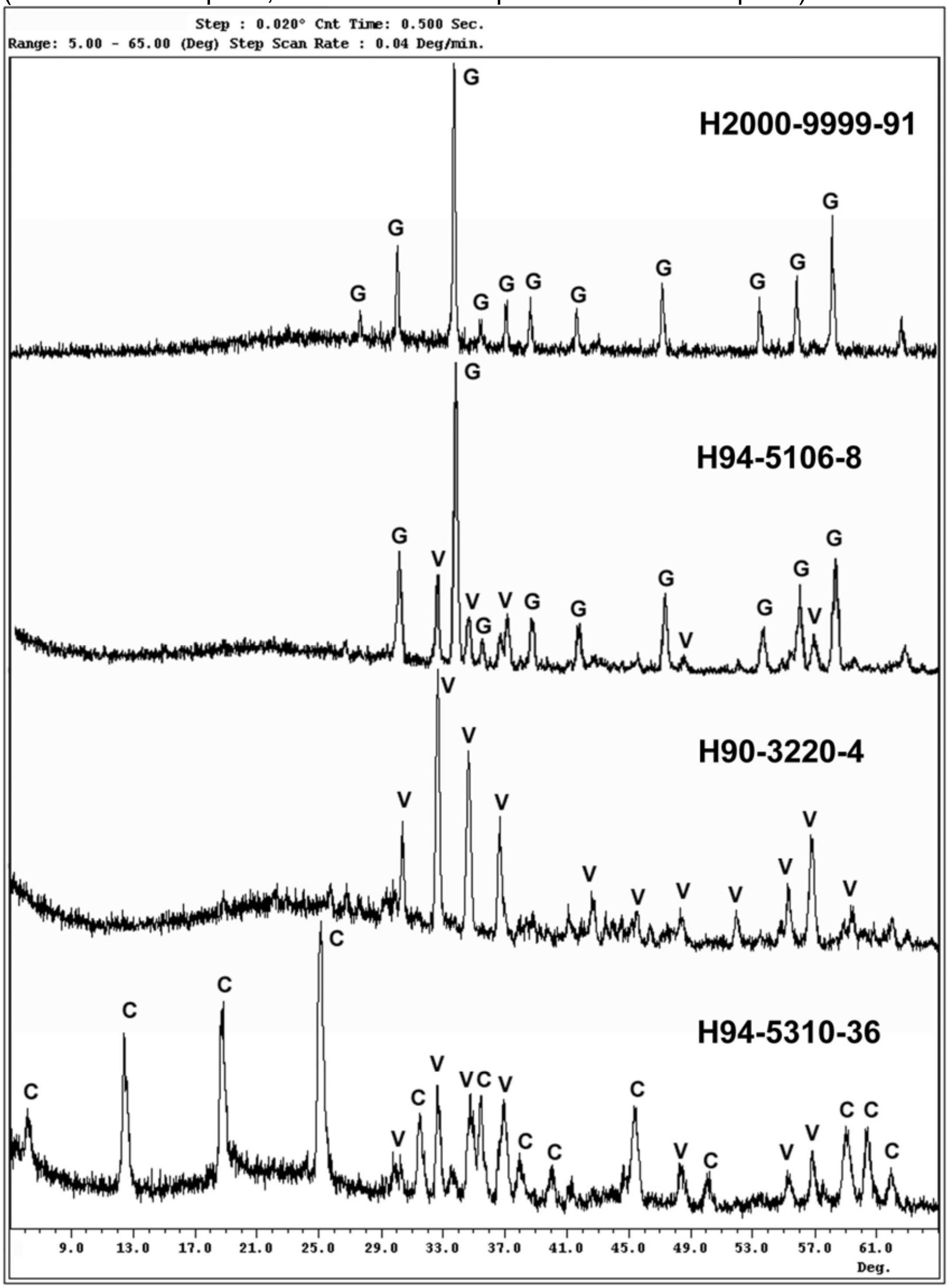


E. Copper ore fragment H95/4943-8 (M = **Malachite** peak)



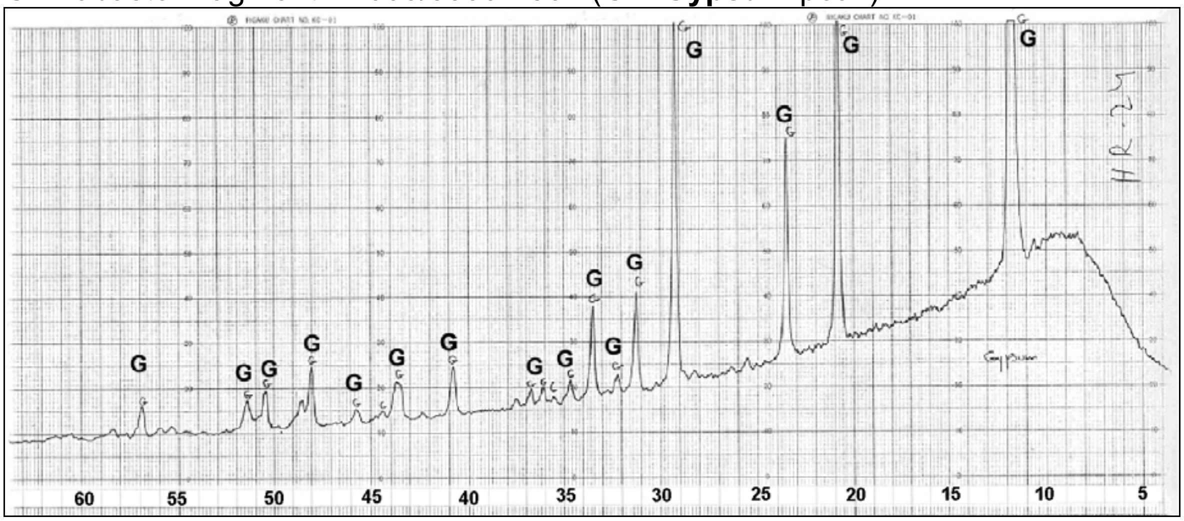
Appendix 4.2 (continued): Representative XRD scans

F. Composite of four XRD scans of vesuvianite-grossular garnet fragments. (G = **Grossular** peak, V = **Vesuvianite** peak. C – **Chlorite** peak)

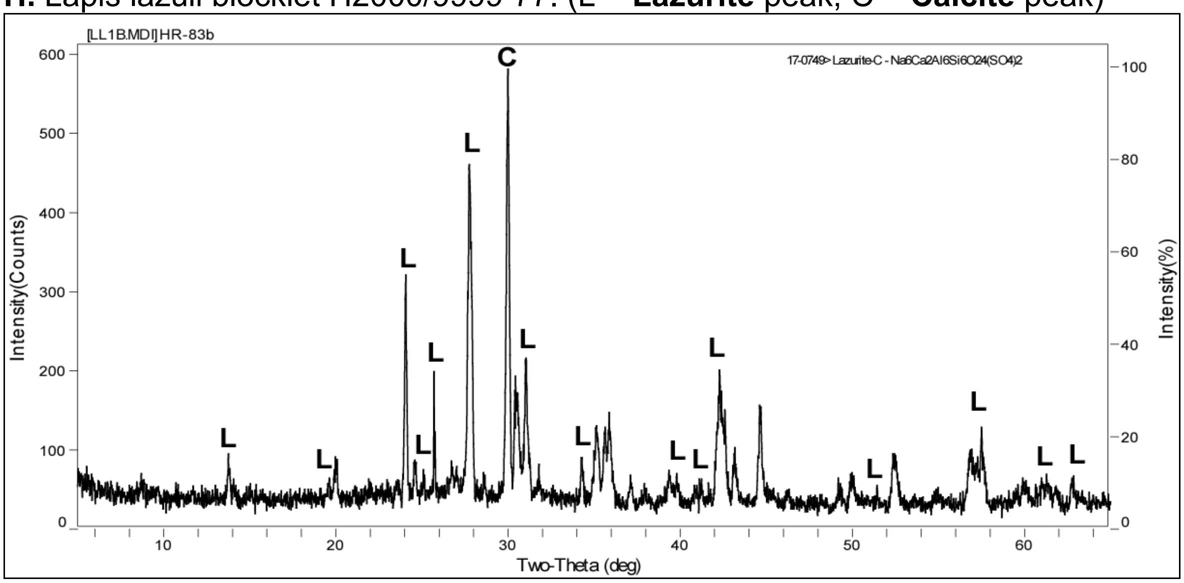


Appendix 4.2 (continued): Representative XRD scans

G. Alabaster fragment H2000/9999-130. (G = **Gypsum** peak)

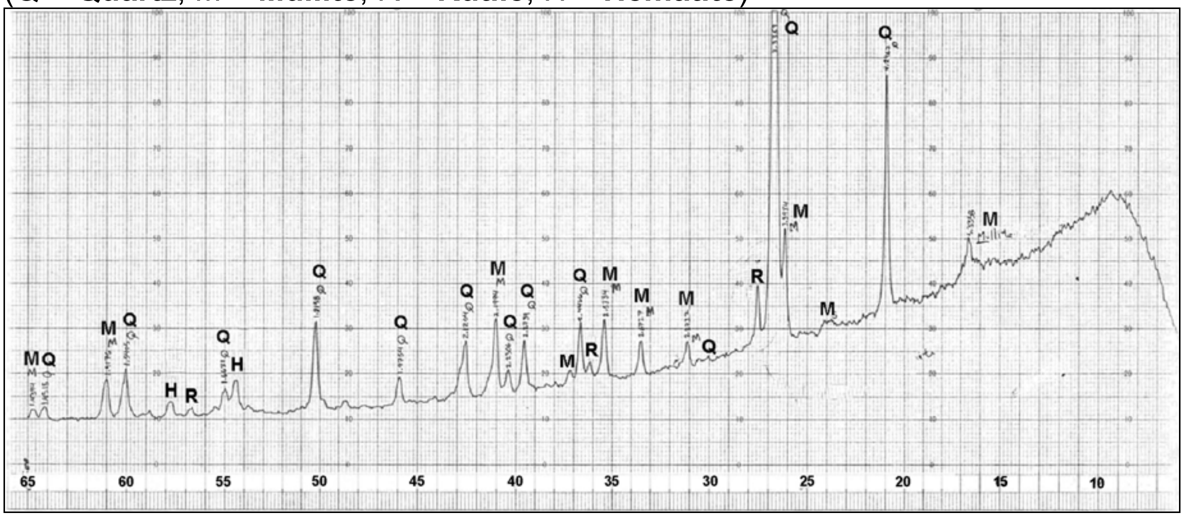


H. Lapis lazuli blocklet H2000/9999-77. (L = **Lazurite** peak, C = **Calcite** peak)

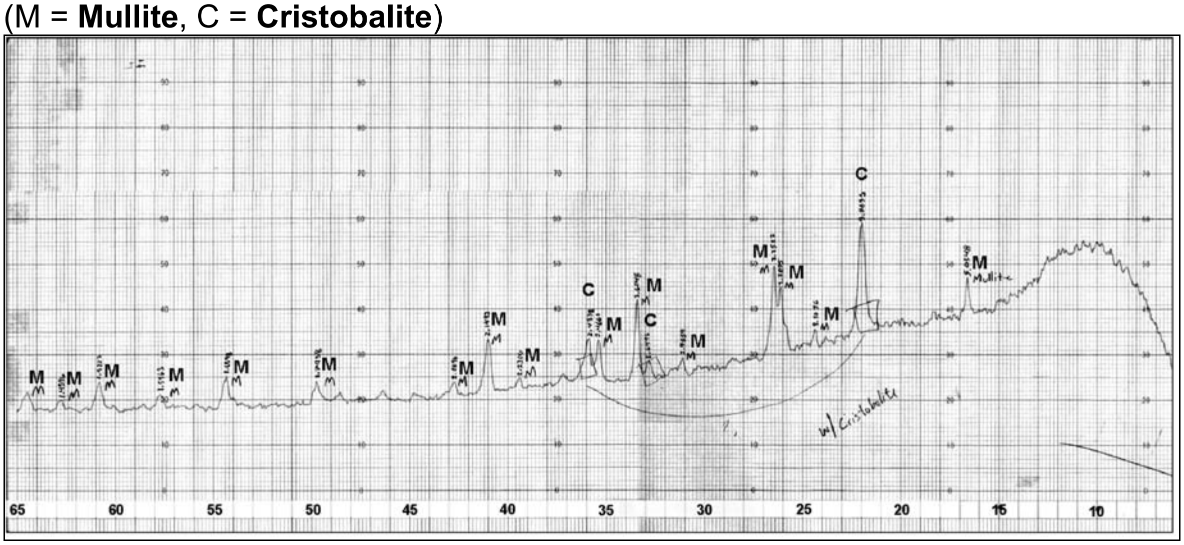


Appendix 4.2 (continued): Representative XRD scans

I. "Ernestite" fragment H2000/3317-4
(Q = **Quartz**, M = **Mullite**, R = **Rutile**, H = **Hematite**)

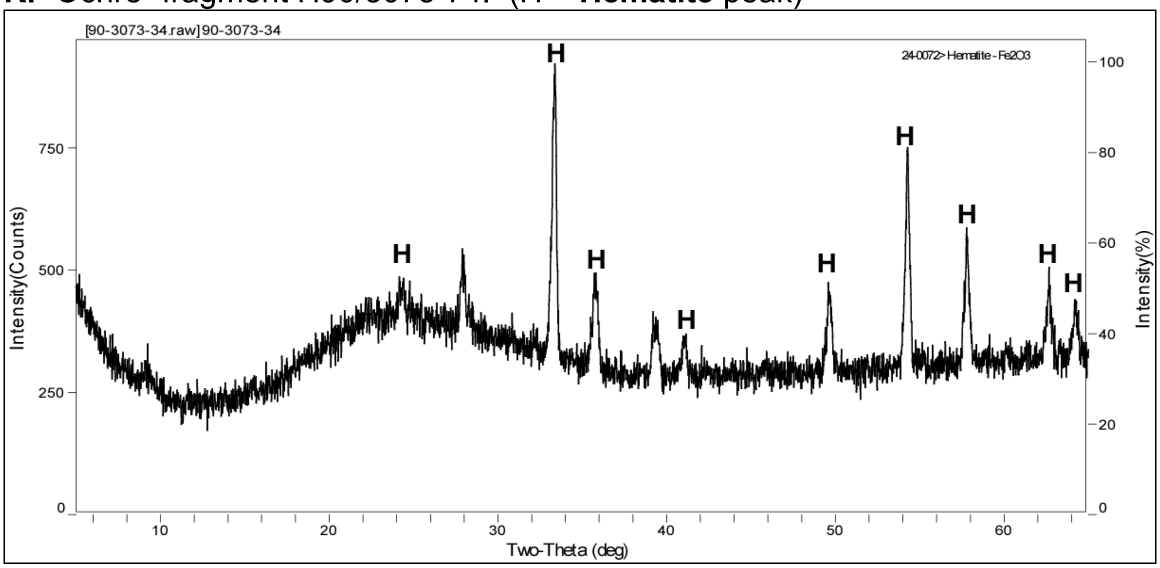


J. "Ernestite" fragment H2000/3317-3
(M = **Mullite**, C = **Cristobalite**)

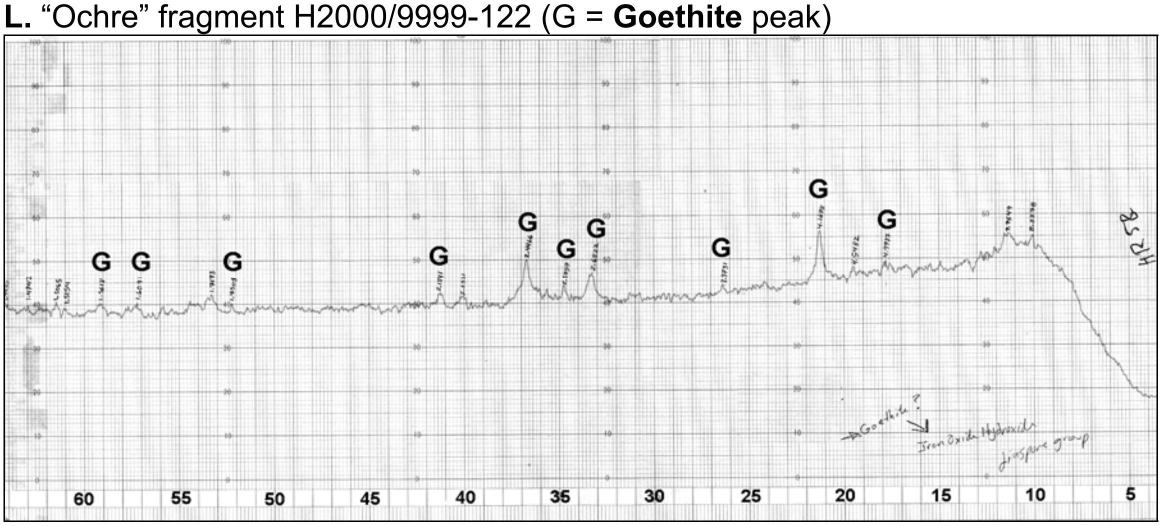


Appendix 4.2 (continued): Representative XRD scans

K. "Ochre" fragment H90/3073-74. (H = **Hematite** peak)

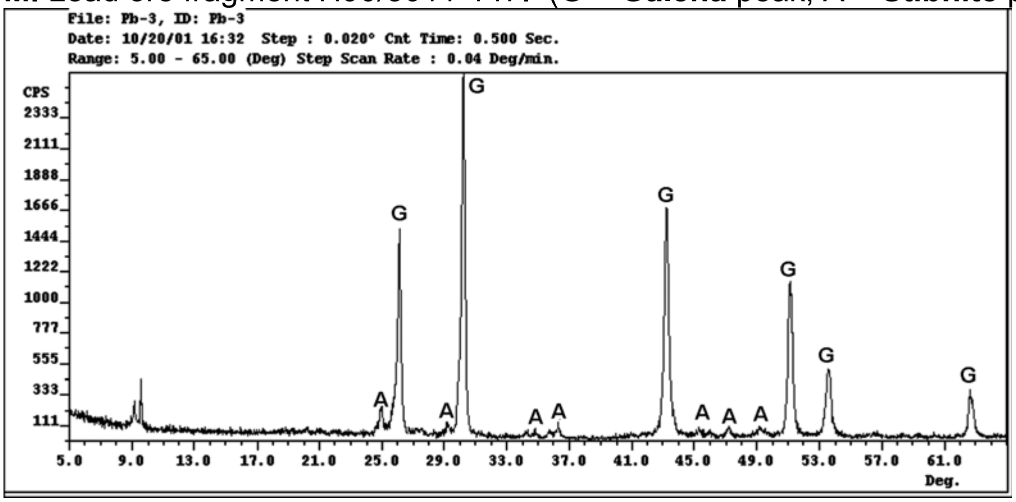


L. "Ochre" fragment H2000/9999-122 (G = **Goethite** peak)

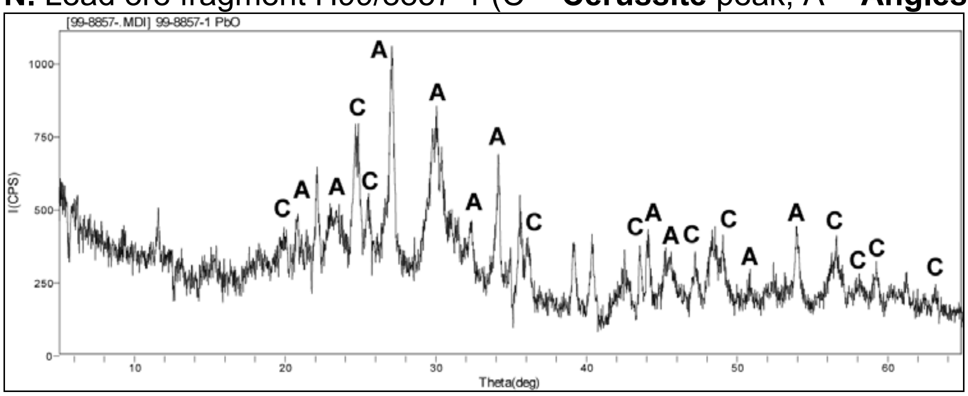


Appendix 4.2 (continued): Representative XRD scans

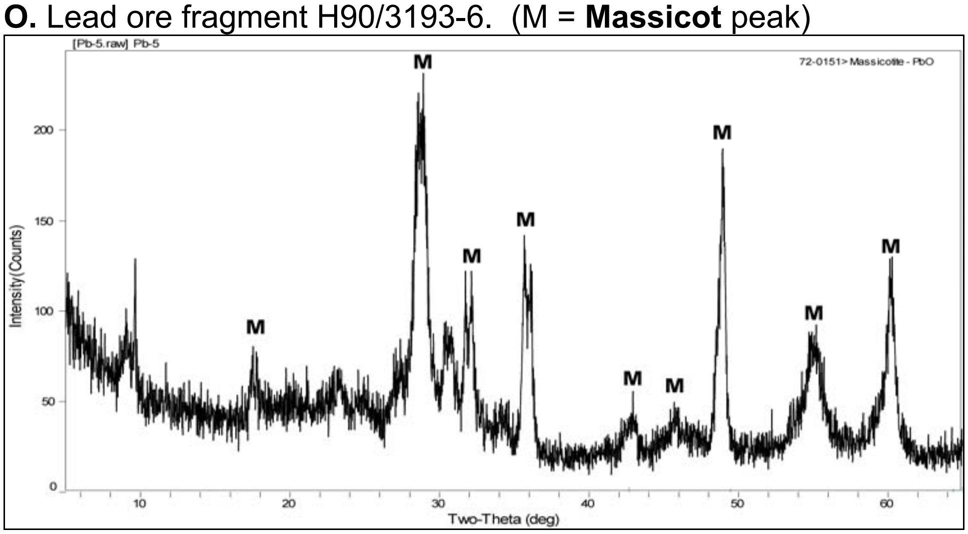
M. Lead ore fragment H90/3011-147. (G = **Galena** peak, A = **Stibnite** peak)



N. Lead ore fragment H99/8857-1 (C = **Cerussite** peak, A = **Anglesite** peak)

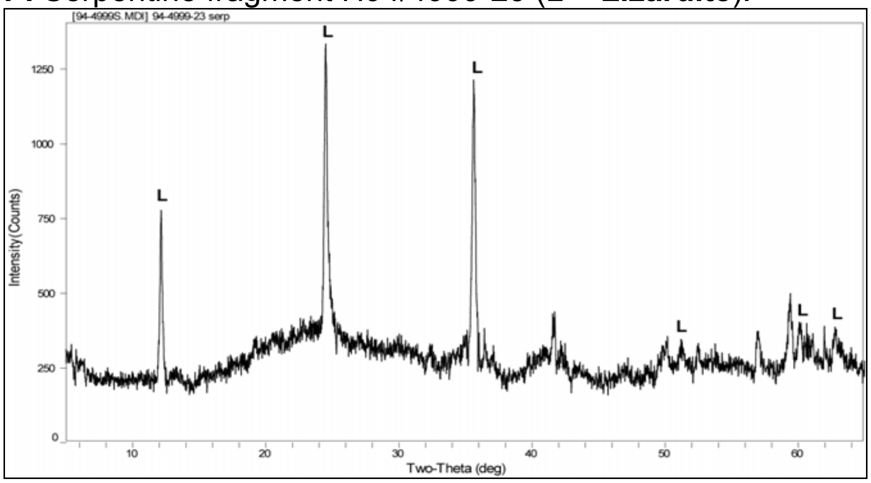


O. Lead ore fragment H90/3193-6. (M = **Massicot** peak)

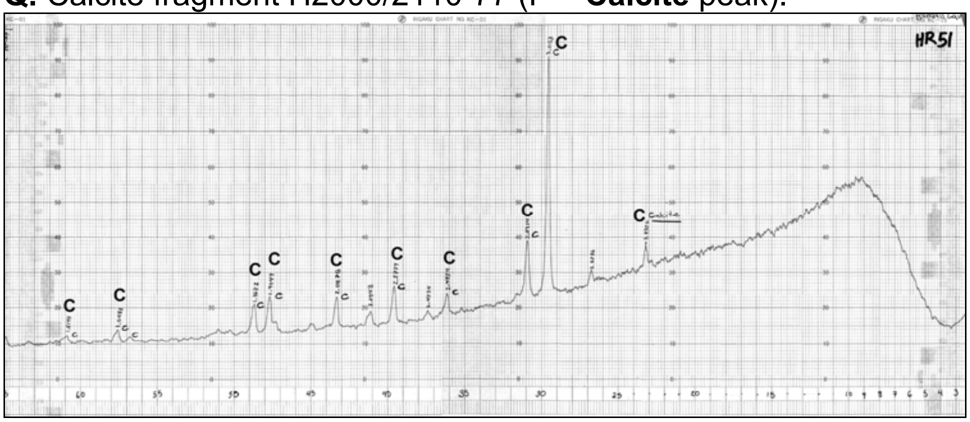


Appendix 4.2 (continued): Representative XRD scans

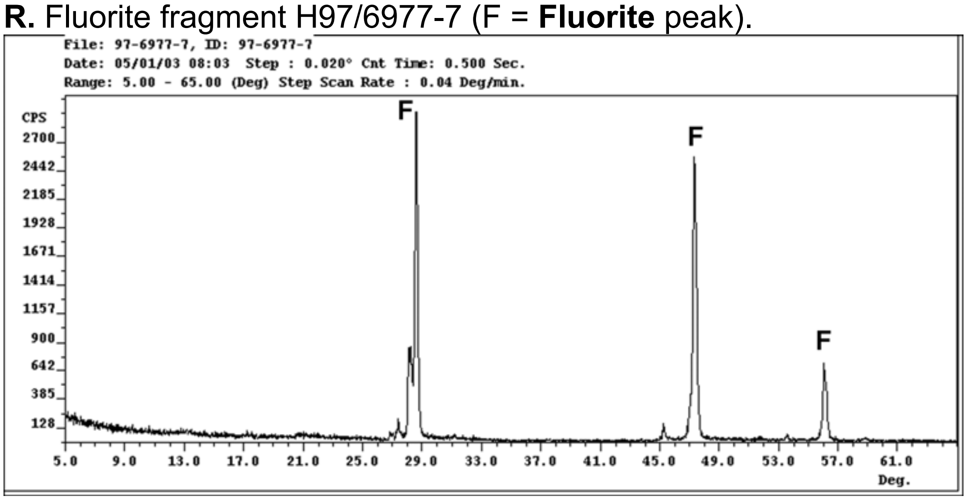
P. Serpentine fragment H94/4999-23 (L = **Lizardite**).



Q. Calcite fragment H2000/2110-77 (F = **Calcite** peak).

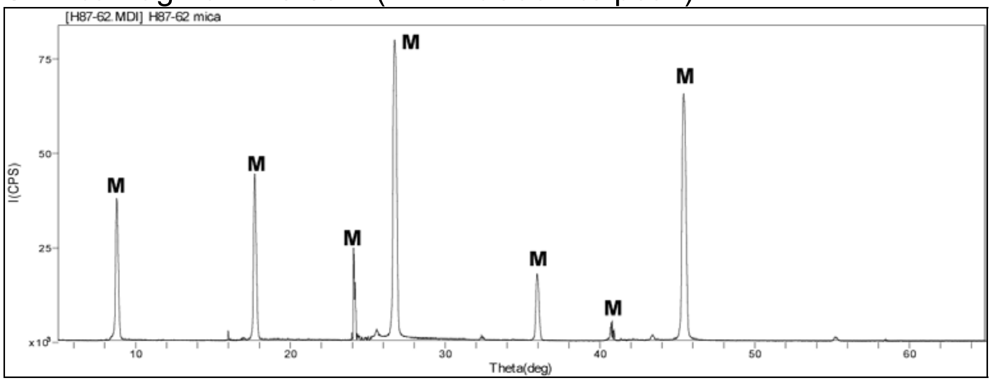


R. Fluorite fragment H97/6977-7 (F = **Fluorite** peak).

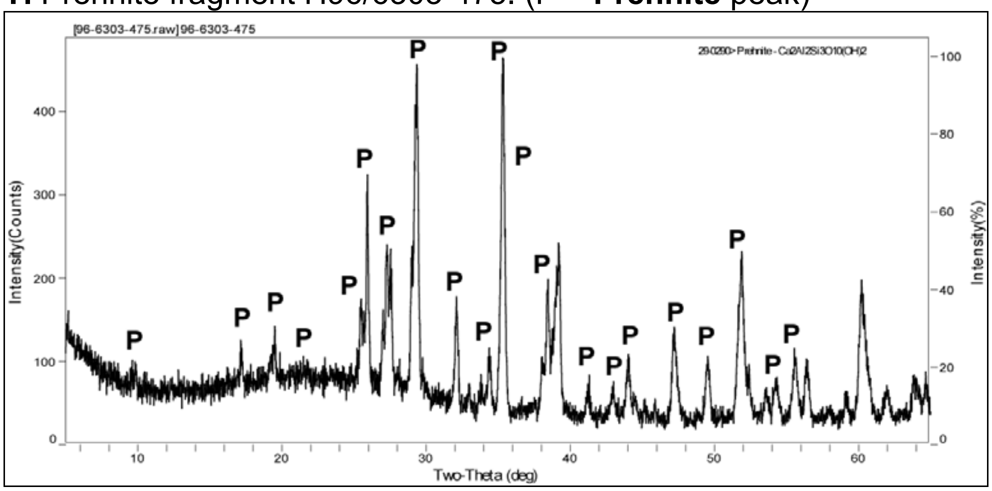


Appendix 4.2 (continued): Representative XRD scans

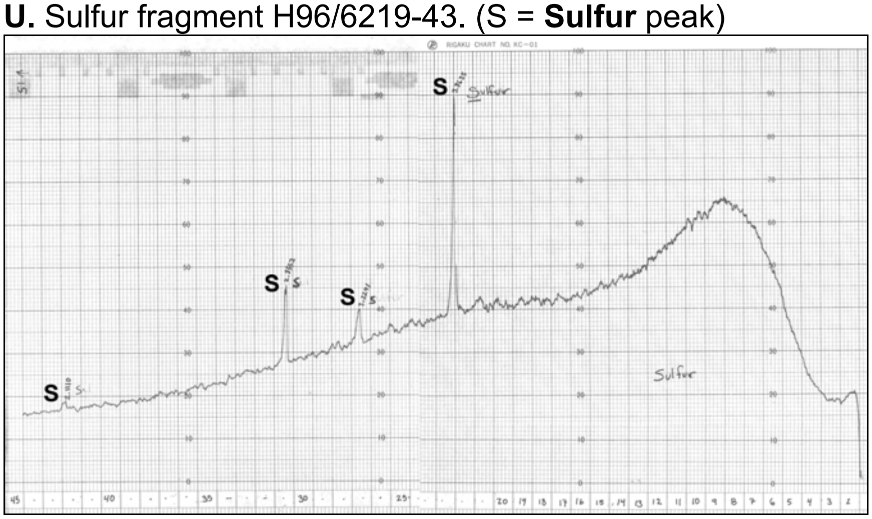
S. Mica fragment H87/62. (M = **Muscovite** peak)



T. Prehnite fragment H96/6303-475. (P = **Prehnite** peak)

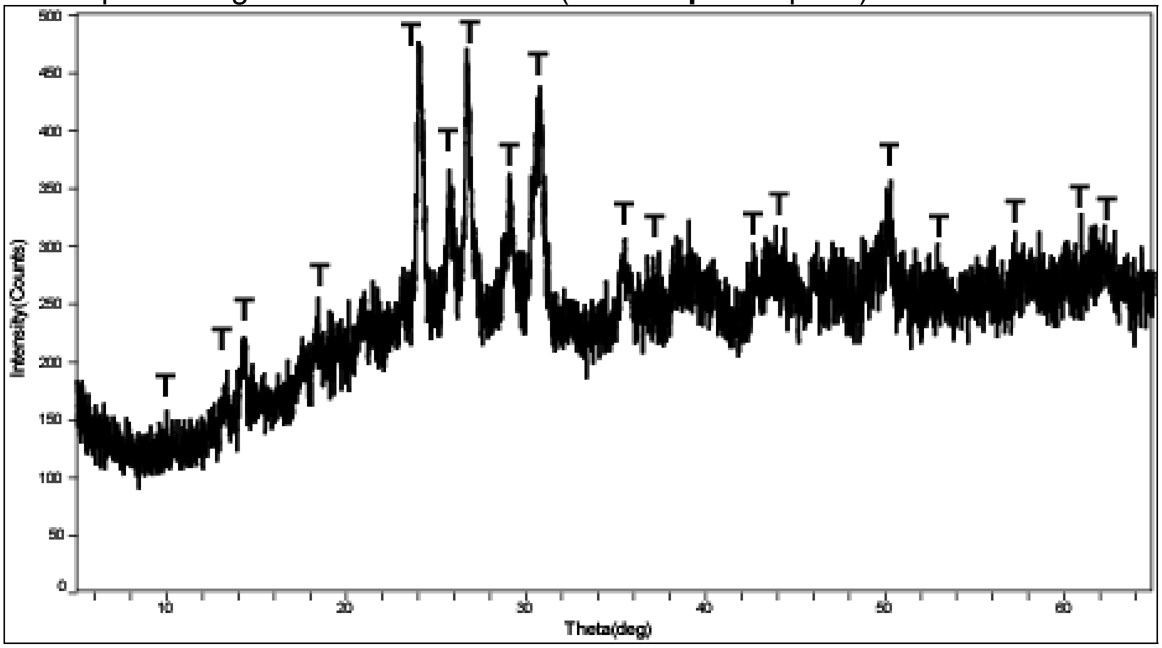


U. Sulfur fragment H96/6219-43. (S = **Sulfur** peak)

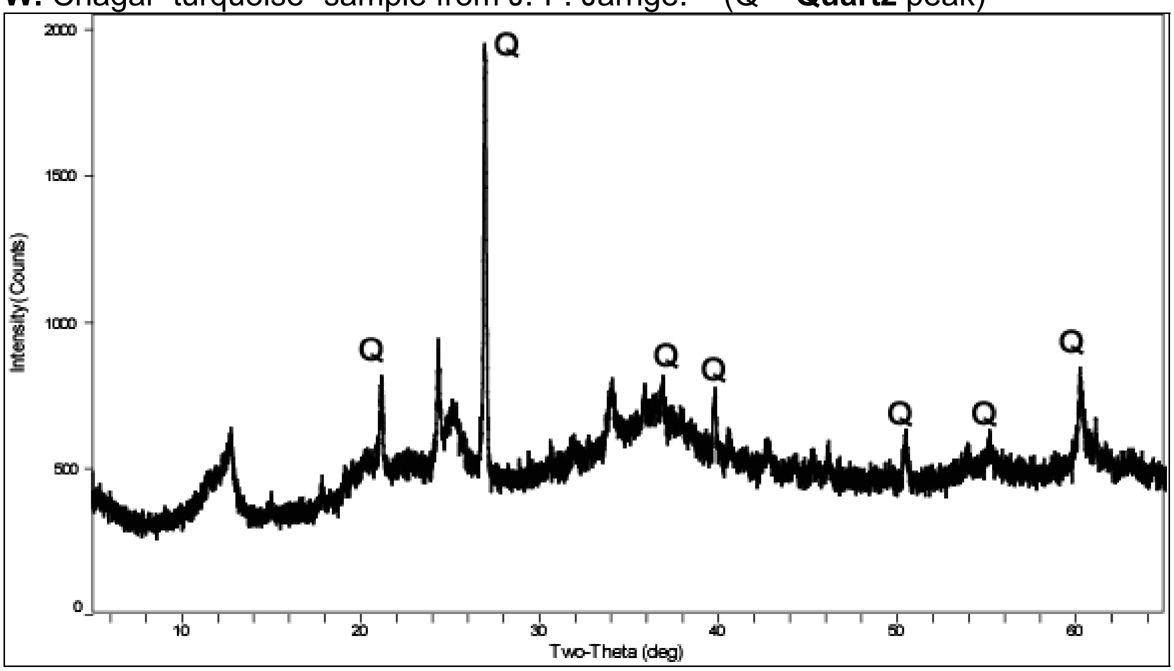


Appendix 4.2 (continued): Representative XRD scans

V. Turquoise fragment H94/4999-213. (T = **Turquoise** peak)



W. Chagai "turquoise" sample from J.-F. Jarrige. (Q = **Quartz** peak)



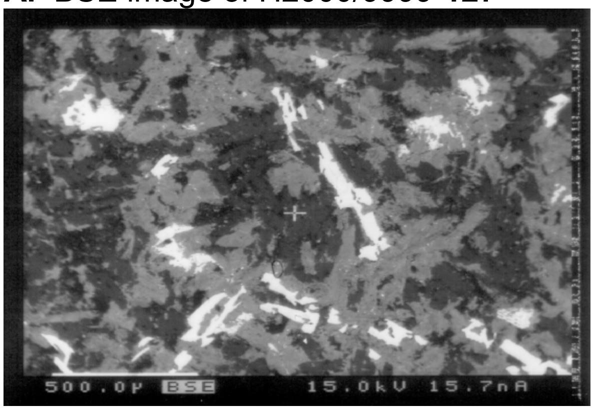
Appendix 4.3: Characterization of two basalt artifacts using EMPA

Basalt is a dense, dark-colored volcanic rock that is composed mainly of plagioclase and pyroxene minerals, but which may sometimes contain significant amounts of olivine (Lapidus and Winstanley 1990: 53). By using EMPA to study the chemical compositions of clinopyroxene crystals in samples, geologists can often identify the tectonic settings (continental, island arc, ocean floor) in which rocks of this kind most probably formed (LeBas 1962; Nisbet and Pearce 1977). Leanne Mallory-Greenough and others (1998) successfully employed this method to characterize and determine the regional geologic provenience of minute pieces of basalt temper in an Egyptian potsherd. Two fragments of basalt recovered from surface contexts at Harappa were selected for exploratory EMPA (Appendix 4.3 Figure 1) to see if similar results could be achieved for artifacts from an Indus Civilization site. Both artifacts were examined using the electron microprobe's back-scatter electron (BSE) imaging and wavelength dispersive spectrometry (WDS) features.

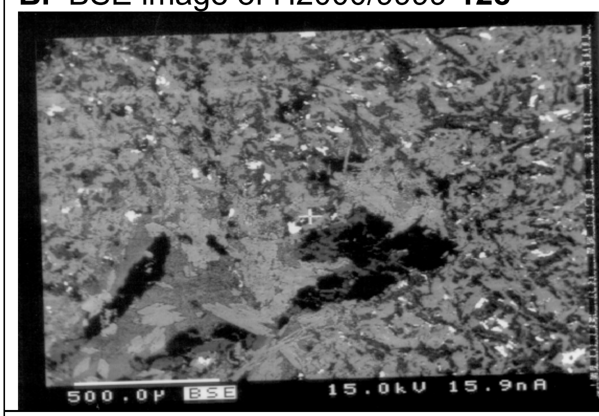
The first artifact examined – H2000/9999-127 (pictured in the third image of Figure 4.4 B), is a large basalt flake that appears to have broken from a pestle or rubbing-stone. The BSE image (Appendix 4.3 Figure 1 A) shows that pyroxene minerals (gray phases) partially surround lathe-like plagioclase crystals (lightest phases), giving the stone a slightly *sub-ophitic* texture (Shelley 1993: Figure 1.17a) that is somewhat reminiscent of *dolerite* (the intrusive equivalent to basalt). WDS scans were made on clinopyroxene crystals at 16 different points extending across the sample. The second artifact examined – H2000/9999-128 (not pictured), is a small, non-diagnostic chunk of basalt. Its BSE image (Appendix 4.3 Figure 1 B) revealed a much finer, inter-granular texture than that of the

Appendix 4.3 Figure 1: EMPA characterization of two basalt fragments from Harappa.

A. BSE image of H2000/9999-**127**



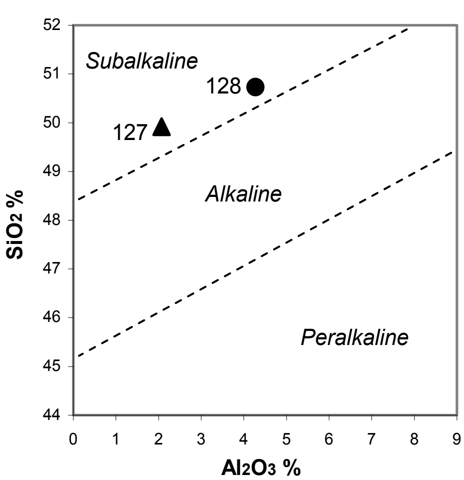
B. BSE image of H2000/9999-**128**



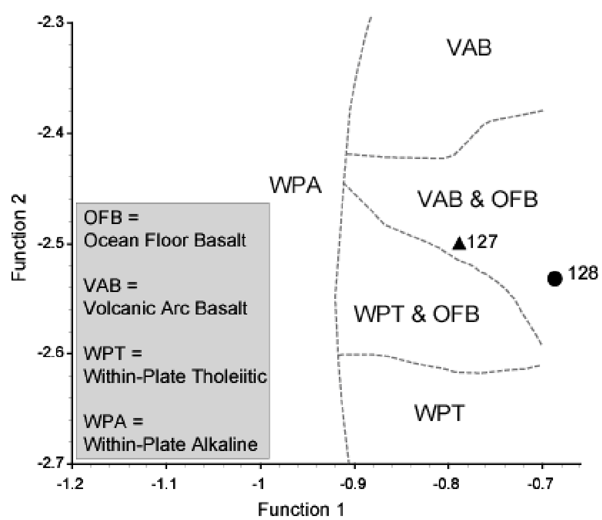
C. Composition of clinopyroxene of crystals in the two basalt fragments

	H2000/9999-**127** (average of 16 analysis points)	H2000/9999-**128** (average of 15 analysis points)
Al_2O_3	2.07	4.28
CaO_2	14.56	11.04
FeO_2	17.63	14.19
MgO_2	13.02	14.82
MnO_2	0.43	0.26
Na_2O	0.26	0.44
SiO_2	49.92	50.73
TiO_2	0.87	0.30
totals	98.80	96.23

D. Silica/alumina plot of Harappan basalt fragments clinopyroxenes compositions (boundaries after LeBas 1962)



E. Harappan basalt artifact clinopyroxene composition data plotted in relation to basalts from different tectonic settings. (Functions and boundaries after Nisbet and Pearce 1977)



first example, one that is quite typical of basalts (ibid.: Figure 1.31b). For this sample, WDS scans were made on 15 different clinopyroxene crystals. Eight oxides were measured and the results of all scans were averaged for each artifact. These data are reported in Appendix 4.3 Figure 1 C.

One way that geologists classify igneous rocks like basalt is according their *alkalinity* – a term which, in this instance, refers to the relative abundance of silica to sodium or potassium- rich minerals in a sample (McBirney 2007: 38-45). The silica and aluminum composition of clinopyroxene crystals in a basalt sample has been shown to be indicative of the alkalinity of the magma from which it formed (LeBas 1962). Using the averages of their measured SiO_2 and Al_2O_3 abundances, the Harappan artifacts are plotted on Appendix 4.3 Figure 1 D in relation to dashed lines that demarcate the approximate boundaries between sub-alkaline, alkaline and peralkaline volcanic rocks (ibid.). Both fall clearly into the *sub-alkaline* category. Basalts of this kind are the most common rocks in oceanic crust (Lapidus and Winstanley 1990: 510) and so the artifacts might very well have originated in one of the ophiolite sequences (obducted oceanic crust) found intermittently to the north and west of the Indus Basin. However, sub-alkaline basalts are known to sometimes occur in volcanic formations associated with continental and island-arc settings.

Using canonical discriminant analysis and data on the same eight oxides measured here, Nisbet and Pearce (1977) compared a large set (n = 329) of volcanic rocks from four different geologic settings: OFB – ocean floor basalts; VAB – volcanic arc (or active continental margin) basalts; WPT – within-plate (continental) tholeiitic basalts; and WPA – within-plate alkali basalts. Reasonably good separation between the four grouped sub-sets

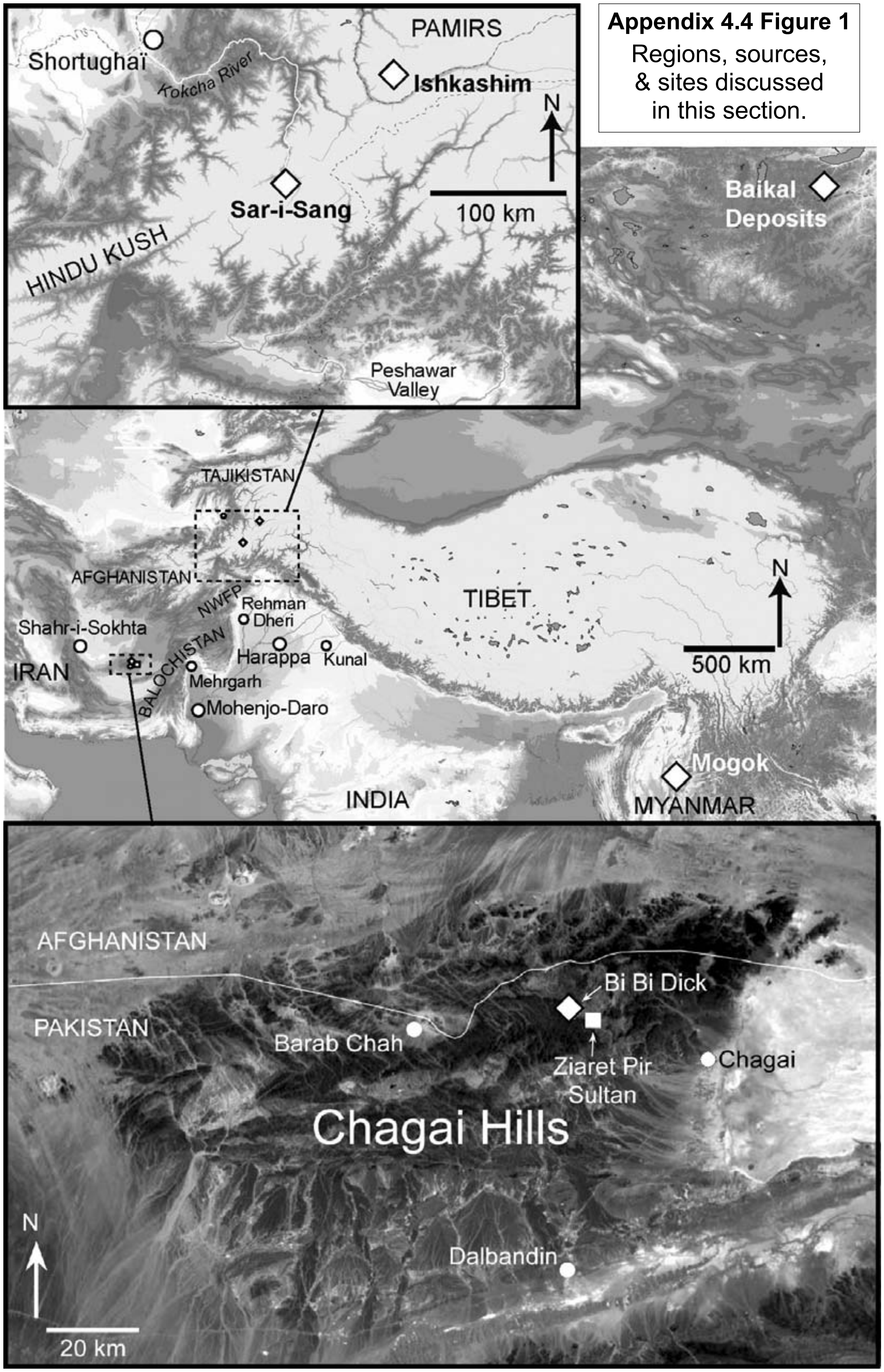
was achieved (the average correct classification success rate was around 70%) and, using the first and second discriminant functions, they created a visual plot with boundaries roughly demarking the zones where samples from the various geologic settings fell (ibid.: 153). Mallory-Greenough and others used a version of this plot (1998: Figure 6) in their effort to identify the geologic provenience of basalt temper fragments. I have created another version (Appendix 4.3 Figure 1 E) upon which the two Harappan basalt artifacts are plotted using the discriminant functions published by Nisbet and Pearce (1977: 152). Both samples fall within the combined VAB and OFB zone.

This preliminary study indicates that the two fragments of dark-colored stone examined here are sub-alkaline basalts that likely came from volcanic formations associated with either oceanic crust (ophiolites) or subduction zones (at island arcs or active continental margins). Although this leaves open a wide range of potential geologic sources around northwestern South Asia (most of them on the northern and western margins of the Greater Indus Valley region), it is possible to state, with reasonable confidence, that these artifacts are probably *not* related to the continental flood basalts of peninsular India and Gujarat known as the Deccan Traps. Whole rock analysis (Mallory-Greenough and Greenough 2004) and potassium-argon dating (Weinstein-Evron et al. 1995) have shown promise in helping to more narrowly define the probable regional provenience of basalt artifacts and may eventually be employed in future studies on these and other objects made of that stone from Harappa.

Appendix 4.4: The Lapis Lazuli Question

"Where did the lapis lazuli come from?" This was the first question that the late Prof. Farzand Durrani asked me after I explained my project to him at a gathering at the University of Peshawar back in late 2000. He, of course, knew of Georgina Herrmann's seminal study (1968) in which she had evaluated all of the known and reported Old World sources of lapis lazuli and concluded that deposits in the Badakhshan area of northern Afghanistan were likely the only ones exploited in ancient times. He had assumed that the raw stone for the numerous lapis lazuli artifacts he had excavated at the Early Harappan site of Rehman Dheri on the Gomal Plain (Durrani 1988; Durrani et al. 1991) originated in Badakhshan, around 475 km due north of the site. In recent years, however, there had been reports of another lapis lazuli source in western Balochistan. Prof. Durrani was, therefore, quite interested to learn if this "new" source, which was supposedly around 675 km to the west-southwest of Rehman Dheri, was genuine. I did not have a satisfactory answer for him at the time. I said that I too had heard about this other source but that I was having a difficult time finding any information on it at all. I said that I would work on the question.

After five years I have come to the same conclusion that Georgina Herrmann did four decades ago. Deposits in the Badakhshan region of northern Afghanistan would have been the *only* viable sources of lapis lazuli for peoples in ancient northwestern South Asia or their contemporaries in Iran, Mesopotamia and Egypt. In this appendix, I briefly discuss lapis lazuli use in ancient South Asia and then present all of the information that led me to that conclusion. Appendix 4.4 Figure 1 is a map with insets that shows the regions, lapis lazuli sources (both genuine and questionable) and sites that are mentioned in this section.



Appendix 4.4 Figure 1
Regions, sources, & sites discussed in this section.

Lapis lazuli in ancient South Asia

The earliest evidence for the use of lapis lazuli in South Asia (or anywhere else) comes from Mehrgarh, where a few small beads were unearthed in burials dating to the seventh millennium BC (Jarrige 1991b: 41). By the time Harappa was founded, roughly three thousand years later, this stone was being transported through exchange networks that brought it to sites across Balochistan (Besenval 2000: 170; Hargreaves 1929: 33-34; Tosi and Vidale 1990), the NWFP (Khan et al. 1991a: 58-59) and into Cholistan (Dogar 2001: 11). Debris fragments from early Ravi Phase strata at Harappa indicate that the fourth millennium BC residents of that site on the Punjab Plain were also participants in those exchange networks and acquired at least some of that stone in raw form.

Lapis lazuli was traded over an even wider area of northwestern South Asia during the Early Harappan and Harappan periods (for information on sites where it has been found see Asthana 1993: 271-273; Chakrabarti 1978; Lahiri 1992; and Ratnagar 2004: 185-193). However, artifacts made of this material tend not to be found in great abundance at those sites where they are present (a few notable exceptions are mentioned below). Case in point – Mohenjo-daro, which was located at the nexus of long-distance trade routes and was home to a large population of affluent elites who, presumably, sought to differentiate themselves through the consumption of exotic materials. Only a pitiful few (perhaps less than a dozen in total) lapis lazuli artifacts have been recovered at that city (Mackay 1931c: 525; Mackay 1938: 499; Pracchia et al. 1985: 236; Bondioli et al. 1984: 24). Because of its apparent limited use there and at most other Indus Civilization sites, the stone is often thought of as being a material that, for various reasons (discussed by Shaffer 1982: 193;

Kenoyer 1998: 96; Vidale 1989b: 180), was "never as highly esteemed in India as in ancient Egypt or Mesopotamia" (Buddruss 1980: 26). Such assessments are probably fair. The tremendous value that some ancient Near Eastern societies placed on lapis lazuli during the fourth and third millenniums BC and the large amounts of that material they consumed is clearly evident in the textual and archaeological records of that region (von Rosen 1988, 1990). The high demand for this stone in Mesopotamia seems to have been an important stimulus for trade across the Iranian plateau during that time (Sarianidi 1971; Tosi 1974a) and a key aspect of the economies of certain settlements located in that region – most notably Shahr-i-Sokhta, a Helmand Tradition site where large quantities of lapis lazuli were evidently prepared for export (Tosi 1974a: 15).

The utilization of lapis lazuli by protohistoric South Asian peoples was, in comparison to many of their contemporaries in regions to the west, undeniably less intense. Even so, I am hesitant to believe that it was an unimportant or even a particularly rare material during the Harappan period (although its greatly limited use at a settlement as large and centrally located as Mohenjo-daro is problematic) simply because it is found across such a wide area and, at a few sites at least, it was rather abundant. Nearly 500 lapis lazuli beads and fragments were recovered at Rehman Dheri (Durrani et al. 1995a) and more than 5500 were part of a single large cache at Kunal (Khatri and Acharya 1997: 86). Although steatite and agate-jasper were clearly the most preferred materials for making ornaments at Harappa, if the major rock and mineral varieties are excluded from consideration (refer back to Figure 4.2 in Chapter 4), then lapis lazuli artifacts occupy a fairly prominent place in the remaining assemblage of that site. The 104 debris fragments

found in Harappan levels at Shortughaï in northern Afghanistan (Francfort 1989: 145, 173), appear to indicate that, during the Harappan Period, Indus peoples had direct access to, (some have suggested even controlled - see Asthana 1993: 273; Ratnagar 2004: 189) a major source of that material located in the nearby Badakhshan region (discussed below). That lapis lazuli was, in general, used sparingly in Greater Indus region at that time is less important in terms of the current study than the fact that Harappans appeared to have had good access to it and that it was present at many sites. Identifying the potential geologic source(s) of such a widely used stone is the main concern here.

Potential sources

Lazurite is a rare mineral in nature (Hogarth and Griffen 1976b: 2). Where it is found, it typically occurs as specks, masses and, occasionally, crystals in zones of marble formed where impure limestone was metasomatized by intrusive granitic rocks (Deer et al. 1992: 502). The only *well-documented* lapis lazuli sources in Asia are: the Sar-i-Sang area deposits in the Badakhshan District, Afghanistan (Bowersox and Chamberlin 1995: Chapter 3; Faryad 2002; Kulke 1974; Herrmann 1968: 22-27; Wyart et al. 1981; Yurgenson and Sukharev 1985); a very small occurrence in the Ishkashim region of the Pamir Mountains, Tajikistan (Ivanov and Sapozhnikov 1985: 14-18; Lutniski 1955; Ostroumov et al. 2002; Sapozhnikov 1992); and a series of deposits in Siberia southwest of Lake Baikal (Bauer 1904: 442-444; Hogarth 1970; Ivanov 1976; Ivanov and Sapozhnikov 1985: 5-14; Ostwald 1963). By well-documented I mean that there are published photographs, precise geographic coordinates, descriptions of mining areas, geologic section drawings, studies of the host rocks and numerous mineralogical analyses of lapis lazuli

samples from those locations. There is not a shred of doubt that these occurrences actually exist. Deposits located in the Mogok area of Myanmar (Bender 1983: 208; Brown and Judd 1896: 213; da Cunha 1989: 69-70), although poorly documented, are most probably genuine. Various older reports and rumors of lapis lazuli occurrences in India, Iran and Egypt are, however, almost certainly spurious (Aston et al. 2000: 39; Herrmann 1968: 27; Karanth 2000: 209). Almost two decades ago a deposit supposedly located in the Chagai Hills of western Balochistan, Pakistan was first brought to the attention of scholars (Jarrige 1988: 28). It is now frequently cited as a potential source for the lapis lazuli used in antiquity (Kenoyer 1998: 96; Lahiri 1992: 22; Possehl 1999: 236; Ratnagar 2004: 185) and samples purported to be from there have even been used in geologic provenience studies of artifacts made of that stone (Casanova 1997). An occurrence in this region could, *if genuine*, have tremendous implications for studies of trade and interaction between the ancient peoples of the Indus region, eastern Iran and southern Afghanistan. I have, however, serious doubts as to whether or not lapis lazuli actually exists in the Chagai Hills.

Doubts about a source of lapis lazuli in the Chagai Hills

The first mention of lapis lazuli in the Chagai Hills that I am aware of are those relating to explorations in the region during the mid-1980s by Jean-François Jarrige, leader of the French Archaeological Mission to Pakistan, and Usman Hassan, a now deceased Pakistani ex-military officer who was a friend of Jarrige's and who had a keen interest in archaeology (Jarrige 1988: 28; Jarrige and Hassan 1989: 160-162). The deposit they reported is said to exist at a location called Bi Bi Dick, approximately 56 km north of Dalbandin, near the Pakistan-Afghanistan border. Jarrige himself never actually visited the

location (Jean-François Jarrige *personal communication* 2003) but somehow Hassan obtained samples said to be from there. Those samples were analyzed by the Geological Survey of Pakistan and confirmed to be genuine lapis lazuli (Khan et al. 1985). Whether or not Hassan himself actually visited the supposed source to collect the samples is unclear. Jarrige believes that he may have but no account of the source/mine was ever given such as the one Hassan published about old lead workings in the Khuzdar District (Hassan 1989). Neither is there any mention of it be found in his posthumously published collection of observations on the archaeology and history of Balochistan (Hassan 2002).

I have conducted exhaustive searches of the geologic literature relating the Chagai Hills but, to date, have found no reference to either lazurite or lapis lazuli in that region. I have spoken with numerous geologists at the Geological Survey of Pakistan (GSP), at the University of Balochistan-Quetta, and several working for private firms operating in the Chagai Hills region about the possibility of lapis lazuli being found there but no one had ever seen or heard of such an occurrence. Moreover, all of them questioned if it were even geologically possible for it to form in the Chagai Hills, which are mostly composed of andesitic volcanic rocks (Bannert 1995: 19). Lazurite forms in contact metamorphosed limestones and then only under exceptional conditions. Rich polymetallic (copper, lead, zinc, molybenite and gold) ores occur in and to the west of the Chagai Hills and, because of that, the region is one of the better surveyed and mapped parts of Balochistan (Allan Spector and Associates Ltd. 1981; Dykstra and Birnie 1979; Hunting Survey Corporation 1960; Nagell 1975; Taghizadeh 1974; Vredenburg 1901). I consulted the published GSP map that covers the area around Bi Bi Dick (Ziaret Pir Sultan quad sheet 34 C/7) where the

source is said to be located and others covering adjacent areas (Barab Chah quad sheet 34 C/3 and Chagai quad sheet 34 C/11). There is nothing on them to indicate that anything other than volcanic rock is found there. Lapis lazuli simply should not occur in the Chagai Hills given what is known about the geology of that region. The samples attributed to a source near Bi Bi Dick that Usman Hassan had analyzed by the GSP were most definitely genuine lapis lazuli, however. How could Hassan have obtained that stone from the Chagai Hills if it were geologically impossible for it to occur there? Dr. Wazir Khan of the GSP-Quetta offered a possible explanation (*personal communication* 2001). He related that a tremendous amount of narcotics smuggling and other clandestine trade took place across the Pakistan-Afghanistan border in western Balochistan, particularly through the rugged Chagai Hills region. Marble, travertine and other types of stone are frequently brought to Quetta from Afghanistan and, rather than having to pay duty on imported goods, those transporting the stone attribute it to sources in the Chagai District. Lapis lazuli from "Chagai" can be found in the Quetta bazaar (I have even purchased some). Dr. Khan suggested that Hassan's samples may have been some of this smuggled material.

The story of "Chagai lapis" does not end there, however. Using atomic absorption spectrometry, Michèle Casanova compared lapis lazuli artifacts from proto-historic sites in Iran (Shahr-i-Sokhta and Tépé Sialk) to geologic samples from several sources in Asia including eleven purported to be from the Chagai Hills (Casanova 1992, 1997; Delmas and Casanova 1990). She obtained the "Chagai Hills" samples from Prof. Maurizio Tosi (Casanova 1997: 15) who was in possession of a collection of lapis lazuli, supposedly from that region, given to him by Emmanuel Lizioli – an Italian living in Pakistan who had

business investments in the onyx marble (variegated calcite) quarries of the western Chagai District (Maurizio Tosi *personal communication* 2005). Sadly, like Usman Hassan, Mr. Lizioli is no longer living and he left no record of how he obtained the samples. For this reason, the provenience of the "Chagai Hills" lapis lazuli samples analyzed by Michèle Casanova must be considered unsubstantiated.

In 1984, Prof. Tosi visited the Chagai Hills region and attempted to reach the lapis lazuli "source" himself. Although he was unsuccessful due to the troubled nature of the area, the local inhabitants that he spoke with at Barab Chah near the Afghanistan border "were quite plain in declaring that blue stone" could be found in the area (Maurizio Tosi *personal communication* 2006). There is no particular reason to doubt that those locals were being anything other than truthful with Prof. Tosi and I am quite sure that they believed the "blue stone" they told him of to be *lazhward* (لاژورد – the Persian word for lapis lazuli that is also used in the various languages spoken in Pakistan). However, through my own personal experience I have come to realize that many people (even some jewellers) are apt to call any variety of bluish-colored rock "lazhward." The "blue stone" that the people at Barab Chah were referring to was, in all probability, *azurite* – a hydrated copper carbonate. As pointed out above, copper mineralization occurs throughout the Chagai Hills region. Geologists that do fieldwork there have shown me photographs of zones of brilliant blue azurite and apple-green chrysocolla (*personal communication* – Abdul Razique and Razzaq Abdul-Manan of Tethyan Copper Limited and the Center of Excellence in Mineralogy, University of Balochistan-Quetta). Those copper minerals can easily be (and frequently are) mistaken for semi-precious stones like lapis lazuli and

turquoise (see my analysis of Chagai Hills "turquoise" in Chapter 4) and are sometimes even used as simulants for them (da Cuhna 1989: 116-17). The same geologists also told me that old pits where azurite and malachite have been extracted in the past can be found at a place called Ziaret Pir Sultan, which just so happens to be located within a few kilometers of the supposed lapis lazuli source at Bi Bi Dick. It is quite probable that accounts of a "lazhward" source in this part of the Chagai Hills actually refer to old those workings or ones like them. Rumors of an occurrence there would have no doubt gained credence when genuine lapis lazuli smuggled from Afghanistan ended up in the bazaars of Quetta and was attributed to this region. Although that is how it may have happened, it is impossible to known for certain. In any case, the existence of lapis lazuli in the Chagai Hills region remains unconfirmed and, geologically speaking, highly unlikely if not impossible.

Michèle Casanova's provenience study of lapis lazuli, although groundbreaking, produced results that were largely inconclusive. The artifacts she analyzed from Shahr-i-Sokhta appeared to be related to geologic samples from northern Afghanistan, Tajikistan and "Chagai Hills" sources (Casanova 1992: 56). Although it is certainly conceivable that material from multiple deposits might be found at that site, the actual assignment of the artifacts to sources was simply not convincing. My reservations about accepting Casanova's provenience determinations lie not with her methods but with her dataset. Its first and most obvious weakness is the great uncertainty surrounding the origins of "Chagai Hills" samples, which made up 11 of the 21 members of the geologic dataset (seven others were from northern Afghanistan deposits, although three were from sources in the former USSR). It is my belief that those particular lapis lazuli samples very likely came from one

of the Badakhshan region deposits in northern Afghanistan by way Lizioli's business associates or other contacts in the Chagai District. Although it is true that Casanova's analyses seem to indicate that there are certain geochemical differences between the "Chagai Hills" samples and the other sources she examined, such differences could easily be due to natural variation between individual deposits *within* the Badakhshan source region itself. Lapis lazuli is mined there at points along an intermittent zone of mineralization that is approximately 20 km long and that ranges from 2000 m to 5000 m in elevation (Hermann 1968: 22-24). Keisch and Callahan's sulfur isotope study (1976) of ultramarine (a blue pigment made from lapis lazuli) included geologic samples from Badakhshan and suggested that there was a great deal of isotopic variability within that zone. Therein is a second area of weakness in Casanova's dataset – the number of samples and their representativeness. The potential range of chemical variability across the extensive Badakhshan lapis lazuli deposits simply cannot be adequately assessed based on the seven samples she analyzed from that source area (Casanova 1992: 50). It is not even clear if those samples represent a single mine or seven individual ones. The same is true, for that matter, of the Badakhshan lapis lazuli samples that showed so much isotopic variability in Keisch and Callahan's study. They wrote that "it would be of considerable interest to analyze samples from each of the mines in Badakhshan" (Keisch and Callahan 1976: 518). This is something that would definitely need to take place in any future provenience study.

One final word on this matter: In being critical of a Chagai Hills lapis lazuli source it was not my intention to impugn the reliability of those who provided the samples attributed to that region (Hassan and Lizioli) or to find fault with Casanova, who I think did

outstanding work given the number and nature of the geologic samples she had available to her. I just believe that this stone is too important to accept anything less than absolute, well-documented confirmation that another source of it existed. The truth of the matter is that I would be thrilled if it were confirmed that lapis lazuli occurred in the Chagai Hills. Having just one possible source is, frankly, a little dull. If lapis lazuli did somehow form in the Chagai Hills then there is reason to expect that it would be chemically and/or isotopically distinguishable from the Badakhshan lapis lazuli. The existence of two sources would have tremendous implications for studies of trade and interaction from South Asia to Egypt. However, all of the available evidence strongly suggests that lapis lazuli does not and cannot exist in the Chagai Hills. I hope to visit the region in the future to confirm this for myself but until that time I will not even consider it as a *possible* source of this stone. Although I would not mind to one day be proved wrong on this matter, I feel that to qualify it in any way would only serve to make the idea that a lapis lazuli source existed in the Chagai Hills of western Balochistan even more indelible than it already seems to be.

The source of lapis lazuli artifacts at Harappa

Assuming that the Chagai Hills are indeed devoid of lapis lazuli (and, for now, I am), then the deposits in Badakhshan, located approximately 650 north-northwest of Harappa in northern Afghanistan, were would have been the only viable sources of that stone for residents of Harappa or other Indus Civilization peoples. The Myanmar and south Siberia deposits, at 2500 km and 3400 km away from Harappa respectively, almost certainly would have been too remote. The occurrence in the Pamir Mountains of Tajikistan, although only around 130 km northeast of the Sar-i-Sang mines, is probably too

minor and too inaccessible (located at 4600 meters in elevation on a precipitous cliff face – Ivanov and Sapozhnikov 1985: 17) to have been an important source. Lapis lazuli is then one of the few materials found at Harappa (the others being marine shell and the remains of oceanic species of fish) that provides unequivocal evidence for both the direction and extent of long-distance acquisition networks during the periods in which they are found.

Lapis lazuli artifacts are have been recovered from every one of the Harappa's chronological phases and sub-phases (Appendix 4.4 Figure 2). Some form of sustained interaction (either direct or indirect) can, therefore, be said to have existed between the peoples of northern Afghanistan and those in this part of the Punjab from the fourth through second millenniums BC. Residents in each area of the site seem to have had access to this material. A little under a one-third (around 29%) of the 174 lapis lazuli artifacts recovered are unfinished beads and fragments of manufacturing debris. Importantly, this evidence shows that this raw material was being transported to the site as early as the Ravi Phase.

Appendix 4.4 Figure 2: Spatial and temporal distribution of lapis lazuli artifacts at Harappa	*fragments, manufacturing debris and unfinished beads*	*finished beads, pendants or ring*
Period 1	3(AB)	1(AB)
Period 2	1(E)	6(AB) 4(E)
Period 3A	ø	21(AB) 3(E)
Period 3B	ø	4(E) 1(ET) 1(cemetery)
Period 3C	2(E) 1(cemetery) 5(ET) 1(F)	8(AB) 7(E) 2(ET) 1(cemetery) 5(F)
Period 4/5	ø	2 (AB)
surface & disturbed deposits	5(AB) 12(E) 5(ET) 3(F) 12(other)	30(AB) 16(E) 2(ET) 2(F) 8(other)
total	**50**	**124**

Appendix 4.5: The "Ernestite" Problem

"Ernestite"

Since commencing work on this dissertation project, I have had numerous debates (sometimes impassioned but always good-natured and constructive) with my academic advisor Dr. Mark Kenoyer regarding the problem of the nature and origins of "Ernestite" – the stone that Harappans used to make constricted cylindrical drills. Prof. Kenoyer feels that it is some unusual type of metamorphic rock, which perhaps has not been previously described by geologists. It was for this reason that he and Massimo Vidale (Kenoyer and Vidale 1992) gave it the informal designation "Ernestite" in honor of Ernest Mackay (*Mackayite* was already being used for another mineral) who first described drills from Chanhu-daro made of this material (Mackay 1937: 6-7). I have had the opportunity to conduct a series of follow-up analyses of "Ernestite" and have come to a different, albeit still provisional, conclusion. My research suggests that "Ernestite" is probably a type of *indurated tonstein flint clay* that has been deliberately heated in order to produce or enhance properties in the stone that made it a highly effective material for drilling hard stone beads. In this appendix section, I present my case for making this designation.

Let me begin by reiterating and expanding my introduction of the material from Chapter 4. "Ernestite" is an extremely fine-grained stone mottled with dark-brown to black patches and dendritic veins in a khaki-colored matrix (refer back to Figure 4.4 H to see a color photograph of raw "Ernestite" fragments). It is hard (easily scratching quartz but not topaz giving it a Mohs hardness of at least 7), very tough (does not break or fracture easily) and fairly dense (SG ranging from ≈ 2.8 for the khaki-colored matrix to ≈ 3.2 for the

brown-black portion). It was fashioned into drill bits with a constricted cylindrical form (Appendix 4.5 Figure 1 A), which were used by Indus beadmakers to perforate hard stone (namely microcrystalline silicates and vesuvianite-grossular). As far as I have been able to determine, stone drills having this distinctive form and appearance are nearly unique to the Indus Civilization. As previously stated, Ernest Mackay (1937) first discovered and studied them at Chanhu-daro in Sindh. Drills of the exact same shape and the raw material used to make them were later identified at Harappa and Mohenjo-daro (Kenoyer and Vidale 1992), as well as at Dholavira in Kutch (*personal observations*, August 2007). The beautifully fashioned black constricted cylindrical drill from Dholavira that is published (as jasper) in the catalog from the "Indus Civilization Exhibition" in Tokyo (NHK 2000: 106, Figure 598) is almost certainly made of "Ernestite." A single drill of this description was found at the site of Ur in Mesopotamia, leading Mackay to speculate that it was "not at all unlikely that bead-making in Sumer was carried on by Indian craftsmen" (1943: 212).

The material that these drills are made from would *seem* to be similarly unique. Using XRD and EMPA, Kenoyer and Vidale (1992) characterized it as a metamorphic rock composed of quartz, sillimanite-mullite and hematite-titanium oxide phases. Unable at the time to identify a known rock type with those phases, they proposed the name "Ernestite."

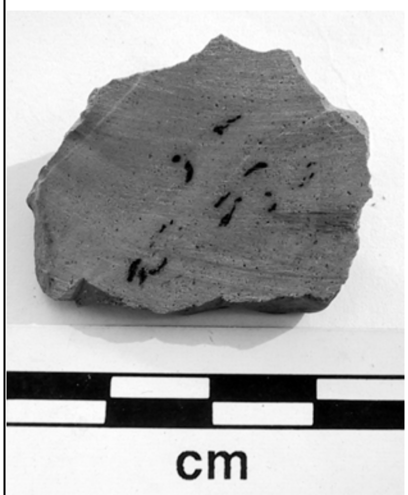
For this study, four "Ernestite" fragments recovered on Mound E at Harappa (H2000/2090-49, H2000/3317-2 to 4) were selected for study using XRD and EMPA with the hope that further characterization might shed new light on the identity of this stone, its geologic origins, potential sources and the properties that made is the most effective material available to Harappans for drilling hard-stone beads.

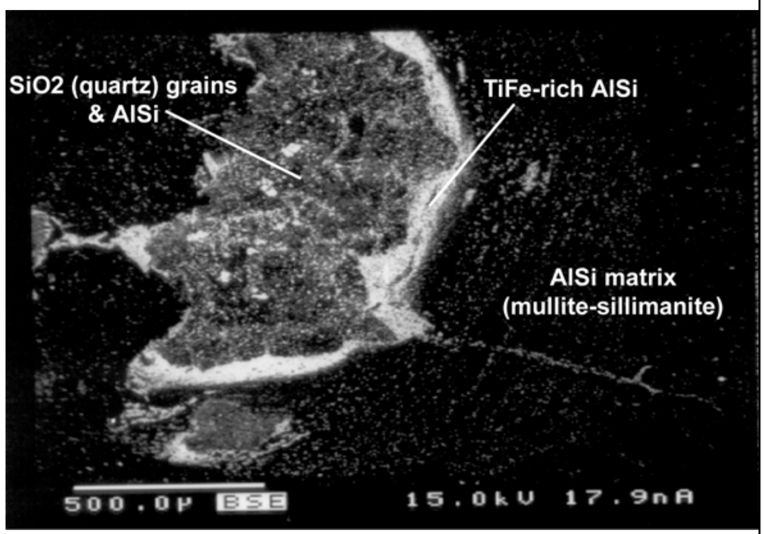
Appendix 4.5 Figure 1: Ernestite from Harappa: artifacts and EMPA of debris fragments

A. Constricted cylindrical drills made from "Ernestite."



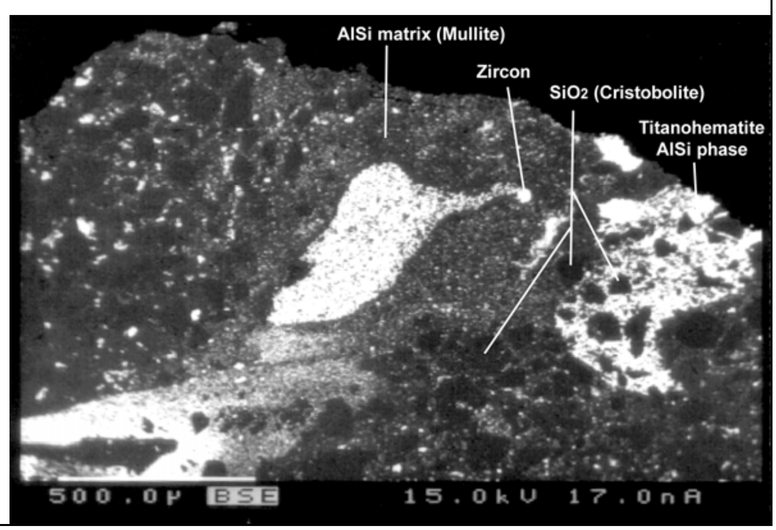
B: "Ernestite" fragment H2000/2090-49 (left). BSE image of black patch (right).





C: Ernestite" fragment H2000/3317-2 (left). BSE image of main body (right).





XRD analysis of "Ernestite"

Two of the four "Ernestite" samples (H2000/2090-49 and H2000/3317-4) examined using XRD were mainly made up of the khaki-colored primary matrix and had only small patches of the black-brown material. These samples displayed diffraction peaks showing that they were composed primarily of quartz and mullite-sillimanite (see Appendix 4.2 I for one of these scans). Minor peaks indicative of *hematite* (iron oxide) and *rutile* (titanium oxide) were also present. *Mullite* and *sillimanite* are actually two separate aluminum silicate minerals that have nearly identical XRD peak profiles (Brown 1980: Table 6.21; Varley 1968: 3). The XRD profiles of the two samples were ambiguous – meaning that they seemed to have peaks characteristic of both minerals and could have been interpreted as either. The same was true of the Mohenjo-daro sample analyzed by Kenoyer and Vidale, which they characterized using a combined term – "sillimanite-mullite" (1992: 507). It is possible that both minerals exist in the samples or, perhaps, than an aluminum silicate phase intermediate to mullite and sillimanite is present (Cameron 1976; Bradley and Roussin 1932). It is also possible that what has been detected in the XRD scans is a poorly crystallized, early stage of mullite formation (Chakraborty et al. 2003).

The remaining two "Ernestite" samples (H2000/3317-2 & H2000/3317-3) were composed largely of the darker material that occurs in veins and patches. The XRD scans unambiguously showed it was the mineral mullite that was present in these fragments (see Appendix 4.2 J for one of these scans). Peaks for quartz, hematite and rutile (present in the previous two samples) were not to be found, however. Instead, strong peaks for *cristobalite* – the high temperature polymorph of quartz, were evident.

The minerals in these samples provide important clues into the possible origins of "Ernestite." Sillimanite occurs in highly metamorphosed *argillaceous* (clay-rich) rocks known as *pelites* (Deer et al. 1992: 52). It is not an uncommon mineral and can be found in rocks of this type occurring at points throughout the Himalayas of northern Pakistan and India (Das 1984; Khan et al. 1997) as well as across Rajasthan (Bhattacharyya 1980; Goel and Chaudhari 1979). Mullite also forms in metamorphosed argillaceous rocks (Deer et al. 1992: 54) but, in contrast to sillimanite, it is an exceedingly rare mineral in nature. To my knowledge, no natural occurrences in South Asia have ever been reported. Mullite is, however, a common man-made mineral. It is both an intentionally produced *refractory* material (a substance able to withstand high temperatures without melting or vitrifying) and a byproduct of certain high-temperature crafts and industries. Mullite can be synthesized when the other aluminum silicate minerals (sillimanite, kyanite and andalusite) are heated to temperatures exceeding 1350ºC (Industrial Minerals 1998: 139). However, mullite also forms when aluminum-rich clays (such as *kaolinite*) and claystones are subjected to sufficient heat – generally this is around 1100ºC but may be somewhat higher or lower depending on the composition of the raw material, the atmosphere and firing dynamics (Brindley and Nakahira 1959; Castelein et al. 2001: 2369; MacKenzie et al. 1996; Russell 1965; Saunders 1958; Schneider et al. 1994: 107). Interestingly and importantly, experimental heating studies (Dubois et al. 1995; Donley 1955: 3; Liu 1990: 5; Lundin 1958; Russell 1965: 45; Worrall 1975: 16) of kaolinitic clay bodies reveal that amorphous silica, which is freed during kaolinite-to-mullite conversion, will crystallize as cristobalite. This has been observed at temperatures as low as 1100ºC (Brindley and Nakahira 1959).

The mineral quartz alone will also convert to cristobalite when heated. Experimental studies (using controlled atmospheres and sample purities) have shown that this conversion occurs slowly between 900ºC and 1200ºC and rapidly after 1300ºC (Sosman 1965: 132-133). Like mullite, cristobalite is a common mineral byproduct in certain high-temperature craft industries. Cristobalite has been previously detected in studies of Harappan craft items such as stoneware bangles (Vidale 2000: 90), faineance objects (McCarthy and Vandiver 1991: 502) and in fired steatite beads (Barthélémy de Saizieu 1994: 56).

The advanced pyrotechnological capabilities of Indus craftspeople are well-documented (Miller 1999) and the presence of these two high-temperature minerals in the "Ernestite" samples analyzed here would seem to suggest that it may have been yet another of the many materials that Harappans heat treated. If it was, then what type of stone might the original material have been? Further characterization studies were conducted using EMPA in order to address this question.

EMPA of "Ernestite"

The four "Ernestite" samples from Harappa, as well as the one from Mohenjo-daro studied by Kenoyer and Vidale in 1992, were examined using the backscatter electron (BSE) imaging, energy dispersive spectrometry (EDS) and wavelength dispersive spectrometry (WDS) capabilities of the electron microprobe. Appendix 4.5 Figure 1 B and C are labeled BSE images of portions of two of the "Ernestite" fragments, which may serve as visual references as I discuss the mineral phases and inclusions (labeled on the figures) that, in most cases, were detected in each of the five samples. Appendix 4.5 Figure 2 is a table of WDS scans that were selected to represent the phases and inclusions identified.

Appendix 4.5 Figure 2: Select WDS scans of "Ernestite" fragments

	Light Matrix	Darker Matrix	Fe Phase (Hematite)	Ti Phase (Rutile)	Titanohematite Phase	SiO_2 Phase
MgO	0.05	0.20	0.18	0.00	0.26	0.00
Al_2O_3	39.25	48.10	6.36	0.50	4.94	0.19
SiO_2	59.28	40.56	7.25	0.30	1.24	98.57
CaO	0.04	0.59	0.03	0.00	0.00	0.00
TiO_2	0.21	0.25	1.56	95.66	33.39	0.08
MnO	0.00	0.00	0.07	0.01	0.06	0.00
FeO	1.07	4.61	74.45	1.00	51.85	0.22
Na_2O	0.06	0.90	0.01	0.00	0.00	0.00
K_2O	0.08	0.64	0.01	0.01	0.02	0.01
Cr_2O_3	0.01	0.02	0.30	0.07	0.14	0.00
total	*100.04*	*95.87*	*90.21*	*97.55*	*91.89*	*99.07*

WDS scans of the primary, khaki-colored matrix (the darker phases in the BSE images) of "Ernestite" showed it to be composed of clay-sized (< 2 μm) or smaller particles of an aluminum silicate (Al-Si) mineral. This would be the phase identified in the XRD scans as mullite or mullite-sillimanite. The darker matrix (lighter phases in the BSE images) that occurs in veins and patches is also an Al-Si phase. However, in some samples this matrix is rich in hematite (iron oxide) and/or contains small phases or inclusions hematite and rutile (titanium oxide). In other samples, an oxide of titanium and iron called *titanohematite* is interspersed among the darker Al-Si matrix. Titanohematite only begins to form at temperatures of around 1050ºC (Deer et al. 1992: 541). It is highly significant that this phase is evident in the same samples (H2000/3317-2 & H2000/3317-3) in which two other high-temperature minerals (mullite and cristobalite) were identified using XRD.

Among the light and dark Al-Si matrixes that make up the main body of ernestite are sub-euhedral grains and fragments of SiO_2 up to 100 μm in size. These are the quartz or cristobalite phases detected in the XRD analyses (EMPA cannot differentiate the two of types of quartz as they are chemically identical polymorphs). Using EDS scans only, small (≈ 20 μm) inclusions of zircon (the brightest white spots on the BSE image) were identified, as well as occasional minute phosphate phases that contained the rare earth elements (REEs) yttrium (Y) and cerium (Ce).

The texture of "Ernestite," as seen in the BSE images also provides clues to its possible origin. The stone's matrix is composed of randomly oriented clay-sized Al-Si particles into which fairly well-sorted sub-euhedral grains and fragments of SiO_2 are set. These are detrital attributes that point to a rock of sedimentary origin. There is no evidence of characteristics one would expect to see if this was a metamorphosed rock such as foliation, deformation or re-crystallization. Nor are there any obvious metamorphic minerals such as are evident in the massive, compact rock composed of altered sillimanite found near Rewa in northern Madhya Pradesh (Banerjee and Sirgar 1961). Remnants of the prismatic, needle-like structure that is characteristic of sillimanite in thin-section (MacKenzie and Adams 1994: 180-181) can clearly been seen in the Rewa rock (Banerjee and Sirgar 1961: Figure 1). Nothing of the sort is evident in the BSE images of "Ernestite," however. This suggests that the somewhat ambiguous "mullite-sillimanite" phases detected in two samples using XRD is almost certainly *not* heat-transformed sillimanite. Instead, those phases most likely represent a poorly crystallized, early stage of mullite formed from the heating of the clay-sized Al-Si material that makes up the stone's matrix.

What is "Ernestite"?

Based on results of the XRD and EMPA characterization studies, I believe that "Ernestite" is a variety of *claystone* known as a *tonstein* and that it was heat-treated by Harappans to produce properties in the stone that made it an extremely effective material for drilling hard stone beads. In this section, I present my case for making this designation.

Claystone (sometimes called clayrock) is a general term for *non-fissile* sedimentary rocks (those that are not laminated and do not split along bedding planes) that are composed of *indurated* (a term synonymous with lithified or cemented) "clay-size silicate minerals" (Blatt 1992: 490; Lapidus and Winstanley 1990: 108). "Ernestite" – a tough, non-fissile stone primarily made up of clay-sized Al-Si particles, clearly falls into this category. Claystones vary in their origins, compositions and degrees of induration (Loughnan 1978). The variety known as *flint clay* is composed mainly of tightly interlocking kaolinite crystals (Moore and Reynolds 1997: 143), which makes it extremely tough and gives it a very fine-grained to microcrystalline texture along with a conchoidal to sub-conchoidal fracture (Keller 1968). The stone is named as it is because, obviously, these traits provide it with physical properties and an appearance that mimics flint (chert). It can easily be knapped like that material and then further shaped by grinding and engraving. In many parts of ancient North America, flint clay was a popular stone for making ornaments, effigies and, significantly, smoking pipes (Emerson and Hughes 2000; Hughes et al. 1998; Wisseman et al. 2002). Using a claystone of this sub-variety, Harappans could have easily fashioned constricted cylindrical drills by the chipping and grinding method described by Vidale (2000: 56).

Most flint clays are also *fire clays* (although not all fire clays are as highly indurated as flint clay). A fireclay is a common refractory material composed of an aluminous clay mineral (normally *kaolinite*) with small amounts of free silica (quartz) and other impurities (of which iron oxide and anatase are of particular importance here), which can withstand temperatures as high as 1750ºC without vitrifying or deforming (Dodd and Murfin 1994: 120-121, 125; Lapidus and Winstanley 1990: 215). Although kaolinite peaks were not detected in the XRD analyses, there are multiple lines of evidence, in addition to its appearance, toughness and texture, which suggests that "Ernestite" is a type of indurated kaolinitic fire clay that has been heat-treated. To begin with, as has been previously discussed, the heating of aluminous clays and claystones produces very characteristic high-temperature minerals. After 600ºC, the structure of kaolinite becomes disordered and, in a *solid-state* (Castelein et al. 2001; Russell 1965), passes through several amorphous (or nearly amorphous) forms (Leonard 1977) until it begins to re-organize as mullite starting at around 1100º C. The mullite phases detected in the "Ernestite" samples are composed of clay-sized Al-Si particles that, in all likelihood, were once kaolinite, but that have been transformed in this way. Similarly, cristobalite is a common by byproduct of heated refractory clays (Davison and Heystek 1979). The phases of that mineral evident in the "Ernestite" samples with well-crystallized mullite could be a product of kaolinite-to-mullite conversion and/or the high-temperature transformation of natural quartz impurities contained within the original claystone – perhaps a combination both. It is also possible that cristobalite was a component of the original, unheated stone (discussed further below).

Other mineral impurities detected in the samples provide supporting evidence that "Ernestite" is a type indurated fire clay and help to explain the variation that is seen between the phase compositions of the stone's lighter and darker Al-Si matrixes. Iron oxide is an important minor component of fireclays (especially in levels greater than three percent) because it enhances mullite formation by acting as a fluxing element with aluminum silicate (Keller 1968: 116). It was not at all surprising, therefore, when EMPA indicated the darker Al-Si matrix of "Ernestite," which exhibited the best developed peaks for mullite in the XRD scans, had refractory levels of iron oxide (Appendix 4.5 Figure 2 column 3). Mullite was more poorly-developed in the samples composed of the lighter-colored Al-Si matrix, which had lower concentrations of iron oxide (Appendix 4.5 Figure 2 column 2). Another common impurity in fireclay is *anatase* (TiO_2), which is the low temperature polymorph of rutile. Anatase converts to rutile after being heated above 730ºC (Deer et al. 1992: 550). The rutile that was detected using XRD in the two lighter matrix "Ernestite" samples is *perhaps* heat-transformed anatase (it may also have been present in the original, unheated stone – see below). This anatase/rutile would have contributed the titanium component of the high-temperature titanohematite phases detected in the darker matrix samples. The zircon inclusions and phosphate phases containing REEs that were detected using EMPA provide still more clues to the identity and origin of "Ernestite." Fire clays were formed in swampy, non-marine environments either from the accumulation of detrital kaolinitic sediments or from the in-situ kaolinitazation of fallen volcanic-ash (Admakin 2002; Keller 1968; Loughnan 1978). The term *tonstein* is widely used to denote the variety formed in the latter manner (Bohor and Triplehorn 1993). The first studies that

I read regarding claystones of this type were eye-opening, because it was as if I was reading descriptions of "Ernestite." Tonsteins possess *all* of the properties that I have outlined above for fire clays *as well as* zircon inclusions and phosphate phases with concentrations of REEs – two traits that are indicative of their volcanic parentage (Bohor and Triplehorn 1993; Hower et. al 1999). In fact, cristobalite and rutile derived from the diagenesis of volcanic ash are also lithogenetic indicators of tonsteins (Admakin 2001: 24). It is therefore possible that those two minerals were original components of "Ernestite" and did not form due to heating (although heating of the stone still took place as demonstrated by the presence of mullite and titanohematite). Because tonsteins formed in swampy, plant-rich environments, they frequently contain casts of rootlets and other organic materials, which give them a mottled appearance (Bohor and Triplehorn 1993: 26-27). This may account for the dark patches and dendritic veining characteristic of "Ernestite."

In summary, the appearance, toughness, texture (both macroscopic and microscopic) and composition of "Ernestite" are all consistent with the category of highly indurated claystone known as flint clay. Most flint clays are also kaolinitic fire clays that, when subjected to sufficient heat, produce a very characteristic mineral – mullite, which is highly uncommon in nature but a ubiquitous byproduct of high-temperature crafts and industries involving aluminous clays and claystones. Its presence, along with titanohematite phases, strongly suggests that "Ernestite" was *deliberately* heated. Cristobalite and rutile phases detected in the stone may also be products of heat-treatment. Or, they could be further evidence of its volcanic parentage, which is clearly indicated by the presence of zircon inclusions and REE-rich phosphate phases. Kaolinitic claystone

formed from the diagenesis of volcanic ash fallen in a swampy, non-marine environment is known as a tonstein. This is what “Ernestite” appears to be.

At least that is my working hypothesis. I have been unable to find any reference to another type of naturally occurring sedimentary, igneous, or metamorphic rock possessing the same combination of characteristics reported here. Of course it is entirely possible that “Ernestite” is a variety of stone that has not previously been encountered and described by geologists. I consider that to be very unlikely, however. Its physical properties are highly consistent with a tonstein, which belongs to a category of kaolinitic claystones that are well known to geologists. The changes kaolinitic materials undergo when heated are equally well-documented and well understood. Although studies will continue, a *highly indurated tonstein flint clay that has been heat-treated* is the most fitting characterization that can be made for “Ernestite” at this time. The concern now is to determine where exactly Harappans might have acquired raw material of this kind.

Where does “Ernestite” come from?

Tonsteins are variable in terms of their color, texture, mineral constituents and degree of induration (Bohor and Triplehorn 1993). Identifying the precise occurrence(s) that was used as a raw material source for “Ernestite” drills will require a great deal of exploration and sample testing. The latter will be necessary because if “Ernestite” was heat-treated (I believe the evidence demonstrates that it was) then it is very likely that the original, un-heated tonstein, wherever it is located, will have somewhat different visual and physical properties, as any substance composed primarily of clay minerals does prior to being fired. Samples collected from potential sources will first need to be experimentally

heated to determine if the physical appearance and properties of “Ernestite” can be replicated. Then they will need to be fashioned into drills to evaluate their effectiveness at perforating hard stone such as agate and vesuvianite-grossular. The problem of locating potential sources is made somewhat easier by the fact that tonsteins and other fire clays were formed in swampy, non-marine environments rich in organic matter and so are almost invariably found in association with coal beds (Bohor and Triplehorn 1993; Loughnan 1978: 380; Hoehne 1976).

Although the term “tonstein” has, up until now, rarely been used in the geologic literature of South Asia, occurrences of claystones or fire clay seams in coal beds have been noted in many different areas around the Greater Indus region (Bender 1995b: 276; Kazmi 1995a: 206-218; Talati and Desai 1978). In the spring of 2003, I traveled throughout northern Gujarat examining and sampling the many fire clay deposits of that area (Bhatti and Chavda 1977; Rahalkar and Madhukara 1980). One occurrence that I was particularly hopeful might be a raw material source for “Ernestite” is located near Guneri (Chavda and Joshi 1990) in the Lakhpat district of western Kutch, not far (≈ 20 km) from where a Harappan Period site has been identified (IAR 1960-61: 8). The samples of dark gray-colored fire clay collected from that location and the four others I visited in northern Saurashtra, were extremely fine-grained but rather soft (as compared to “Ernestite”). After being fired at 1200ºC for one hour, their colors ranged from light khaki to an almost pure white and, although they became significantly harder, they were light in weight and somewhat brittle. Although these deposits obviously did not provide the raw material that I was seeking, the overall physical appearance of samples from them, aside from their color,

in many ways resembled the larger fragments of "Ernestite" recovered at Harappa. This further convinced me that Harappans were using a variety of sedimentary claystone to make constricted cylindrical drills, rather than a metamorphic rock. I simply had not yet located a coal bed containing a tonstein claystone that was sufficiently indurated to begin with. Other potential occurrences can be found in every province of Pakistan (Kazmi et al. 1990; Shah et al. 1990; Warwick and Husain 1990). Some of those where refractory clays and claystones are noted (Baqri 1978) lay deeply buried and so would not have been accessible to Harappans. Coal beds are, however, exposed on the western flanks of the Kirthar Range in Sindh (Blanford 1879: 192-193) and I have been advised (S.R.H. Baqri *personal communication* 2004) that very hard, flint-like claystones can be found in the vicinity of Sehwan. Claystone seams in accessible coal beds are also reported in the western and central part of the Salt Range (Shah 1980: 82-84; Whitney et al. 1990: 3).

Although the search for Ernestite" will continue in all of the above areas, my feeling at this stage is that the Harappan source likely lies somewhere in northern Gujarat. There are close to 1000 "Ernestite" drill bits in the collection of excavated materials from the site of Dholavira (*personal observations*, August 2007). Compare this to the 75 artifacts in total (both drills and debris) that have been recovered at Harappa. The shear abundance of "Ernestite" at Dholavira would seem to indicate that beadmakers there had access to a local (on Khadir Island) or regional (elsewhere in Kutch) source of the stone.

"Ernestite" as a drill-making material

What properties did heat-treated tonstein flint clay possess that appealed to Harappan beadmakers? Experimental studies by Kenoyer and Vidale (1992) have shown

that it would have been possible for them to perforate a hard stone like carnelian almost three times faster using an "Ernestite" drill bit than it would have been using one made from a microcrystalline silicate like jasper or chert ("Ernestite" abraded carnelian at an average rate of 2.37 mm per hour compared to .83 mm per hour for green jasper). This unequal drilling efficiency probably has little to do with differences in hardness between the two materials. Quartz has a Mohs hardness of around 7 and so does mullite – the hardest major mineral in "Ernestite" (zircon has a hardness of 7.5 but there is not enough of it in the stone to have contributed significantly to its cutting effectiveness). The properties that make "Ernestite" much more effective than chert or jasper for drilling hard stone beads are its *durability*, *strength* and *heat-resistance*.

Harappans would have found drills made of a microcrystalline silicate to be more than effective tools for perforating steatite, lapis lazuli, serpentine or any other variety of stone with a Mohs hardness of less than 7. However, as Kenoyer and Vidale discovered (1992: 504-505), when used on a stone of equal hardness such as agate, both the shaft of the drill and the hole of the bead being perforated wear to a high polish. Abrading effectiveness rapidly diminishes as this occurs. In contrast, the inter-locking clay-sized Al-Si particles of "Ernestite" make it an extremely durable (wear-resistant) material. In the 1930s, C.H. Desch carried out a drilling experiment (noted in Mackay 1943: 211) on carnelian using a bit recovered from the site of Harappan Period site of Chanhu-daro in Sindh. At the time, the bit was thought to be made of chert but it is now known be composed of "Ernestite." After drilling carnelian to a depth of 1 mm in around 20 minutes (an abrading rate roughly comparable to what Kenoyer and Vidale recorded for

“Ernestite”), Desch found the wear on the tool “to be very slight” (ibid.). Scanning electron microcopy (SEM) studies by Kenoyer and Vidale (1992: 508) revealed that drills made of durable “Ernestite” do not become polished during use like microcrystalline silicates. Instead, they maintain a rough micro-surface and, thus, an undiminished cutting capacity.

In addition to being durable, “Ernestite” is an extremely well-bonded material, which can be made into drills that, although delicate-looking, are very strong. Perforating the distinctively Harappan style of long (≈ 7 to 10 cm) carnelian beads was accomplished using a graduated series of three or four long and progressively thinner “Ernestite” drill bits (Kenoyer and Vidale 1992: 511). One example that Ernest Mackay reported (1943: 211 *footnote* and Plate LXXXVI b, #8, drill e) from Chanhu-daro was 1.5 inches (3.81 cm) in length but only 0.12 inches (3.05 mm) in diameter. Although fashioning a drill bit of similar dimensions out of chert or jasper would have been possible, such a tool would likely not have lasted for long under the stress of drilling as the “raw material is very brittle and tends to flake very easily and snap” (Kenoyer and Vidale 1992: 503).

Microcrystalline silicate drills are also plagued by frequent incidences of spalling due to the heat generated by the friction of drilling, as well as a tapered design that makes cooling the tool during use difficult (Kenoyer and Vidale 1992: 505). Heat-spalled drill bit tips made of jasper and chert are very common finds in areas at Harappa where hard stone beads were made (Meadow et al. 2001: 7). A tool made from a refractory material like tonstein flint clay, on the other hand, would be extremely resistant to the effects of heat. The biggest testament to this is that no heat-spalled “Ernestite” drill tips have ever been found at Harappa (J.M. Kenoyer *personal communication* 2002).

The "secret" to "Ernestite's" durability, strength and resistance to heat is mullite. The remarkable mechanical and refractory properties of this mineral are well-documented (Osendi and Baudín 1996; Mah and Mazdiyasni 1983; Schneider et al 1994; Schneider and Komarneni 2005). Mullite "imparts uniformly high strength" to those materials in which it forms, as well as a "high resistance to thermal spalling, i.e, resistance to breaking or cracking when heated" to extreme temperatures (Keller 1968: 119-120). There is a modern industry devoted to deliberately synthesizing it for applications that require a material having this specific combination of properties (Industrial Minerals 1998; Johnstone and Johnstone 1961; Schneider and Komarneni 2005). Mullite would not have been originally present in the tonstein(s) used as a raw material for "Ernestite." That stone likely attracted the attention of Harappans looking for drill-making material because it was already a tough, highly indurated rock (as most flint clays are). Sometime around the middle part of the Integration Era (ca. Period 3B at Harappa), perhaps even earlier, it was discovered that by heating tonstein flint clay to a temperature that probably exceeded 1100ºC it was possible to produce or enhance properties (discussed above) in the rock that made it a superior material for drilling hard stone beads. Although Harappans could not have known that the reason for this was that its structure of tightly inter-locking kaolinite crystals was being made even stronger and more heat-resistant by the solid-state transformation of those crystals into mullite, they were evidently well aware of which parts of the stone had most benefited from the heat-treatment. The majority of finished "Ernestite" drills recovered at Harappa and other Indus sites were made largely or entirely from the stone's less abundant black matrix, which the XRD scans showed have the best developed mullite phases.

Conclusion

There is still great deal of work to be done on the “Ernestite” problem. Although I feel strongly that the identification “tonstein flint clay that has been heat-treated” is currently the best explanation for the macroscopic, mineralogical and mechanical characteristics possessed by “Ernestite,” I realize that many (including myself) will not be entirely convinced of this until a source of tonstein flint clay is located in the Greater Indus region, material from that sources is heated to temperatures that should result in the formation of mullite, then that heat-treated material is fashioned by chipping and grinding into replicas of Harappan constricted cylindrical drills and finally it is shown that those drills are capable of perforating agate or vesuvianite-grossular at a rate of better than 2 mm an hour or better without breaking or spalling. If that can be done and the resulting material *looks* like “Ernestite” then I will be convinced.

Addendum

Having read the above section, Prof. Kenoyer felt that I had not adequately demonstrated that “Ernestite” was heat-treated. He suggested that I heat a piece of it in a muffle furnace to a temperature hot enough for mullite and cristobalite to form (≈ 1100 to 1200º C) in order to see if its appearance changed. He argued that if the material had been previously heat-treated in this way then its appearance after being re-heated should remain unchanged. So I took a small (≈ 1.75 x 2.75 cm) chip off of one of the larger pieces of “Ernestite” and heated it slowly (a dynamic firing where the temperature was steadily raised 200º C per hour) to 1200º C. The chip was allowed to dwell at 1200º C for two hours after which the furnace was turned completely off and left to cool slowly overnight.

Appendix 4.5 Figure 3:
Before and after images of an "Ernestite" chip that has been heated to 1200º C



The next day the "Ernestite" chip was removed from the cooled furnace and examined. Appendix 4.5 Figure 3 is a composite photo that shows the chip's unheated appearance (left) next to how it looked after being fired slowly to 1200º C (right). There is a *slight* difference in the before and after images. The khaki-colored matrix is a shade lighter as are some patches of the darker matrix. I can think of two reasons why the stone's color might have become slighter lighter. Firstly, the chip is from an artifact that has been buried for 4000 plus years. "Ernestite" is dense, yes, but is still basically a claystone that is somewhat permeable. "Ernestite" artifacts may actually have darkened slightly over the last four millennia as they picked up organics from the moisture laden soils at Harappa. Firing the chip may have simply burned off some of the organics it picked up. Moreover (and secondly) the muffle furnace was an oxygen-rich environment. "Ernestite" contains iron phases, the heaviest concentrations of which are in the darker portions of the stone. Had the chip been fired in a reducing atmosphere then the iron oxides in it might have remained dark or, perhaps, even become darker.

In the end, the chip's appearance was little changed and the firing experiment was inconclusive. In my opinion, the biggest testament to "Ernestite's" heat-treatment by Harappans remains the presence of mullite and cristobalite – two minerals that are rare nature (even rarer together) but are common in clays and claystones heated to high temperatures.

<u>Appendix 5.1</u>: All querns and mullers (whole and fragmentary) recovered from excavations and surveys at Harappa from 1986 to 2004.

In the tables below each artifact is first listed by <u>year</u>, <u>lot</u> and <u>record</u> number.

The <u>location</u> from which an artifact was recovered is noted by mound (AB, E, ET, F or LW [low western]), operation (Op.), area (CEM = cemetery, MS = Mughal Sarai) or trench number (for certain off-mound trenches).

An artifact's <u>context</u> is noted by period number (1, 2, 3A, 3B, 3C, 4 or 5) if it was recovered from secure deposits. Context is noted as "S&D" if it came from either surface or disturbed deposits. In rare instances (such as miscellaneous finds turned in by workmen) an artifact's context is not available (n/a).

Designated <u>material</u> type is listed as Pab sandstone (PAB), Delhi quartzite (DQ), Kirana Hills stone (KH) gray sandstone (GSS) or unknown (UNK).

The weight of each artifact is provided in <u>grams</u>.

year	lot	record	location	context	material	grams
86	0.002	27	E	S&D	GSS	290
86	0.004	37	E	S&D	DQ	338
86	0.004	38	E	S&D	GSS	174
86	0.005	96	E	S&D	PAB	462
86	0.006	58	E	S&D	DQ	72
86	0.006	57	E	S&D	UNK	247
86	0.024	216	E	S&D	DQ	143
86	0.024	218	E	S&D	DQ	1000
86	0.024	213	E	S&D	GSS	434
86	0.024	214	E	S&D	PAB	283
86	0.024	215	E	S&D	PAB	228
86	0.024	219	E	S&D	PAB	133
86	0.029	10	LW	S&D	PAB	685
86	0.033	16	E	S&D	UNK	67
86	0.042	63	E	S&D	DQ	8
86	0.042	64	E	S&D	DQ	6
86	0.042	66	E	S&D	DQ	5
86	0.042	67	E	S&D	DQ	3
86	0.042	65	E	S&D	PAB	6
86	0.043	42	E	S&D	GSS	242
86	0.043	41	E	S&D	UNK	327
86	0.043	44	E	S&D	UNK	132
86	0.047	21	E	S&D	DQ	19
86	0.047	22	E	S&D	DQ	14
86	0.047	23	E	S&D	DQ	6
86	0.126	27	AB	S&D	PAB	77
86	0.126	28	AB	S&D	UNK	57
87	3	31	CEM	S&D	UNK	126
87	11	21	CEM	3C	GSS	330
87	33	2	CEM	3C	UNK	435
87	50	1	CEM	3C	UNK	236.2
87	62	68	CEM	3C	DQ	164
87	73	22	CEM	3C	PAB	124
87	127	8	CEM	3C	GSS	173
87	130	1	CEM	3C	UNK	287
87	141	4	CEM	3C	UNK	179
87	144	1	CEM	3B	UNK	72
88	210	1	CEM	S&D	UNK	254.8
88	241	5	CEM	S&D	DQ	127.6
87	300	10	n/a	n/a	PAB	139.7
87	303	11	E	3C	GSS	255
87	303	12	E	3C	PAB	290
88	321	15	E	S&D	PAB	211
88	321	2	E	S&D	UNK	93.5
88	321	14	E	S&D	UNK	132.5
88	322	6	E	S&D	UNK	1490
88	324	2	E	3C	GSS	177.3
88	326	16	E	3C	PAB	649.7

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
88	329	6	E	3C	UNK	38		87	518	50	AB	S&D	GSS	677
88	330	3	E	S&D	PAB	832		87	518	47	AB	S&D	PAB	187
88	334	9	E	S&D	PAB	208.7		87	518	48	AB	S&D	PAB	354
88	340	9	E	3C	PAB	33.7		87	518	49	AB	S&D	UNK	434
88	343	41	E	S&D	DQ	765		87	525	51	AB	S&D	UNK	927
88	343	63	E	S&D	PAB	365.5		87	525	108	AB	S&D	DQ	74.5
88	343	64	E	S&D	PAB	68		87	525	161	AB	S&D	PAB	997
88	343	65	E	S&D	UNK	158		87	525	162	AB	S&D	PAB	374.5
88	344	96	E	3C	GSS	75.5		87	525	163	AB	S&D	PAB	105
88	348	12	E	3C	DQ	3200		87	525	164	AB	S&D	UNK	114
88	348	2	E	3C	PAB	293.5		87	525	165	AB	S&D	PAB	677
88	348	17	E	3C	PAB	124		87	525	166	AB	S&D	UNK	22.7
88	348	20	E	3C	UNK	248.9		87	525	167	AB	S&D	UNK	35.7
88	348	28	E	3C	UNK	248		87	525	168	AB	S&D	PAB	73.5
88	353	17	E	3C	PAB	3200		87	525	175	AB	S&D	UNK	394.5
88	354	66	E	3C	PAB	113.5		88	528	37	AB	S&D	PAB	116.9
88	355	48	E	3C	UNK	192.5		88	528	57	AB	S&D	PAB	167
88	358	12	E	3C	PAB	750		88	528	56	AB	S&D	UNK	92
88	363	11	E	S&D	UNK	65		88	538	6	AB	3C	PAB	170.5
88	365	11	E	S&D	DQ	1074		88	540	3	AB	3C	PAB	465
88	365	11	E	S&D	DQ	1074		88	546	2	AB	3C	UNK	145.5
88	365	10	E	S&D	PAB	1450		88	553	3	AB	3C	PAB	454
88	433	1	CEM	3C	PAB	36		88	559	21	AB	3C	UNK	432
88	433	20	CEM	3C	UNK	57.5		88	572	21	AB	3C	PAB	120
88	436	7	CEM	3C	UNK	120.5		89	586	10	AB	3C	PAB	294
88	436	37	CEM	3C	UNK	29		94	634	1	AB	S&D	KH	118.3
87	501	2	AB	S&D	UNK	97.5		94	645	10	AB	S&D	PAB	995
87	502	5	AB	S&D	UNK	89		94	651	1	AB	S&D	PAB	400
87	503	23b	AB	S&D	PAB	400		94	658	1	AB	S&D	PAB	228
87	503	23	AB	S&D	UNK	235.8		94	699	8	AB	S&D	DQ	9.3
87	505	49	AB	S&D	PAB	336		94	699	1	AB	S&D	KH	173.3
87	508	21	AB	3C	DQ	53.5		88	700	36	E	S&D	PAB	356
87	508	23	AB	3C	DQ	346.6		88	703	7	E	3C	UNK	101.8
87	508	20	AB	3C	PAB	698		88	703	15	E	3C	UNK	178
87	513	4	AB	S&D	GSS	151.1		88	709	36	E	S&D	PAB	356
87	514	22	AB	3C	DQ	204		88	712	1	E	S&D	UNK	134
87	514	11	AB	3C	GSS	572		88	714	17	E	S&D	DQ	385
87	514	10	AB	3C	UNK	524.5		88	714	25	E	S&D	DQ	464
87	514	11	AB	3C	UNK	104.3		88	725	75	E	3C	PAB	391.5
87	515	13	AB	S&D	GSS	1146		88	725	77	E	3C	PAB	512.5
87	516	13	AB	S&D	DQ	166.7		88	725	82	E	3C	PAB	324
87	516	20	AB	S&D	GSS	326.7		88	725	86	E	3C	PAB	458.2
87	516	14	AB	S&D	UNK	393		88	725	125	E	3C	PAB	6500
87	518	15	AB	S&D	GSS	319.8		88	725	128	E	3C	PAB	7
87	518	38	AB	S&D	GSS	220		88	731	8	E	S&D	PAB	370.5

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
88	734	4	E	3C	PAB	733.5		89	1115	5	E	3A	GSS	147
88	746	7	E	S&D	PAB	302.5		89	1115	6	E	3A	KH	322
88	752	3	E	3C	PAB	385		89	1120	11	E	S&D	KH	305
88	767	34	E	3B	UNK	36.2		89	1121	31	E	S&D	KH	27.5
88	767	35	E	3B	UNK	36.1		89	1121	32	E	S&D	PAB	33.2
88	769	1	E	3B	PAB	359		89	1121	13	E	S&D	UNK	57.7
88	781	2	E	3B	PAB	426.5		89	1124	7	E	2	KH	72.8
88	783	29	E	3B	UNK	310		89	1135	1	E	2	UNK	86.9
88	797	36	E	3A	GSS	227		89	1136	1	E	2	KH	62.5
88	802	52	E	3C	PAB	25		90	1142	15	E	S&D	UNK	613
88	802	53	E	3C	PAB	24		90	1147	4	E	3A	UNK	60.8
88	1000	5	E	3A	UNK	74.5		90	1147	20	E	3A	UNK	234
89	1013	9	E	S&D	KH	351		90	1150	18	E	2	PAB	30
89	1015	21	Op.6	S&D	UNK	156		90	1150	19	E	2	PAB	124
89	1015	22	Op.6	S&D	UNK	152		90	1152	29	E	3A	KH	187.7
89	1018	15	Op.6	S&D	PAB	590		90	1153	42	E	S&D	KH	160.7
89	1024	18	E	3A	UNK	296.4		90	1156	74	E	2	KH	185.6
89	1027	29	Op.6	S&D	PAB	118		90	1156	75	E	2	KH	134.6
89	1038	25	Op.6	S&D	DQ	186		90	1157	75	E	S&D	PAB	19.3
89	1038	24	Op.6	S&D	PAB	128		90	1157	1	E	S&D	SR	347.7
89	1046	30	E	2	KH	30.6		90	1157	67	E	S&D	UNK	6.6
89	1046	31	E	2	KH	39.4		90	1163	1	E	2	UNK	607.5
89	1054	130	E	S&D	KH	63.6		90	1164	21	E	2	KH	135.8
89	1056	13	E	2	DQ	43.1		90	1170	32	E	2	KH	457.5
89	1056	2	E	2	UNK	102.8		90	1170	34	E	2	KH	90.6
89	1060	112	E	S&D	KH	198.7		90	1174	16	E	2	KH	203
89	1060	113	E	S&D	KH	839		90	1174	17	E	2	KH	209
89	1060	110	E	S&D	UNK	78.1		90	1175	25	E	2	KH	20.8
89	1060	111	E	S&D	UNK	215.3		90	1175	25	E	2	KH	26.2
89	1067	85	E	S&D	KH	114		90	1175	26	E	2	KH	89
89	1067	35	E	S&D	PAB	151		90	1175	31	E	2	KH	211.9
89	1067	34	E	S&D	UNK	130.4		90	1177	5	E	2	KH	506
89	1072	11	Op.6	S&D	UNK	28.3		90	1177	6	E	2	KH	210.2
89	1075	22	E	S&D	GSS	163		90	1178	28	E	3A	KH	54.1
89	1075	21	E	S&D	UNK	244.4		90	1180	15	E	2	KH	42.8
89	1078	8	E	S&D	GSS	126.4		90	1180	16	E	2	KH	64.4
89	1083	31	E	S&D	KH	157		90	1181	16	E	2	KH	141.6
89	1084	6	Op.6	S&D	PAB	154		90	1181	17	E	2	KH	144.7
89	1087	3	E	S&D	UNK	87.4		90	1181	28	E	2	KH	76.4
89	1091	13	E	S&D	PAB	109		90	1182	82	E	2	KH	28.5
89	1101	4	E	3A	KH	249		90	1183	4	E	2	KH	113.4
89	1104	4	E	S&D	UNK	159		90	1187	16	E	2	KH	25
89	1105	9	E	S&D	KH	320		90	1187	17	E	2	KH	50
89	1107	13	E	S&D	PAB	502		90	1187	18	E	2	KH	70.6
89	1110	4	E	S&D	UNK	747		90	1187	19	E	2	KH	59.2

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams	year	lot	record	location	context	material	grams
90	1187	20	E	2	KH	48.7	90	1302	4	E	2	KH	12
90	1187	21	E	2	KH	157.5	90	1303	18	E	2	UNK	34.5
90	1187	22	E	2	UNK	260	89	2000	65	E	S&D	PAB	904
90	1189	7	E	2	UNK	99.9	89	2000	66	E	S&D	UNK	112.5
90	1191	13	E	2	KH	52.7	89	2005	16	E	3A	UNK	8.3
90	1191	14	E	2	KH	37.8	89	2005	65	E	3A	UNK	63.8
90	1191	15	E	2	KH	14.9	89	2006	134	E	S&D	UNK	599
90	1191	16	E	2	KH	4.8	89	2014	4	E	3B	PAB	35.6
90	1191	17	E	2	KH	65.8	89	2033	5	E	3B	PAB	92.1
90	1191	18	E	2	KH	39.4	89	2047	1	E	3A	KH	162
90	1191	20	E	2	KH	339	89	2052	9	E	3B	UNK	247.4
90	1191	25	E	2	KH	21.2	90	2071	9	E	S&D	KH	39
90	1191	28	E	2	KH	85.8	2000	2087	7	E	S&D	PAB	251
90	1191	19	E	2	UNK	180.2	2000	2101	60	E	S&D	UNK	59
90	1197	11	E	2	KH	79.6	2000	2102	310	E	S&D	DQ	50
90	1197	12	E	2	KH	159.3	2000	2102	928	E	S&D	DQ	80.8
90	1197	17	E	2	KH	40.4	2000	2102	1561	E	S&D	DQ	146.6
90	1198	16	E	2	KH	80.5	2000	2102	905	E	S&D	PAB	500
90	1198	19	E	2	KH	12.2	2000	2102	906	E	S&D	PAB	953
90	1200	40	E	2	KH	79.9	2000	2102	1558	E	S&D	PAB	42.5
90	1200	41	E	2	KH	326	2000	2102	1559	E	S&D	PAB	85.3
90	1200	42	E	2	KH	49.6	2000	2102	1562	E	S&D	PAB	126.6
90	1200	43	E	2	KH	252	2000	2102	904	E	S&D	UNK	374
90	1200	44	E	2	KH	152.3	2000	2102	926	E	S&D	UNK	54.7
90	1200	45	E	2	KH	95.3	2000	2102	1560	E	S&D	UNK	90.6
90	1200	76	E	2	KH	20.4	2000	2104	138	E	S&D	DQ	153.2
90	1200	77	E	2	KH	5.9	2000	2104	93	E	S&D	PAB	132
90	1200	12	E	2	UNK	181.4	2000	2104	94	E	S&D	PAB	61.6
90	1207	9	E	2	KH	80.2	2000	2104	96	E	S&D	PAB	34.2
90	1207	8	E	2	UNK	89.6	2000	2104	139	E	S&D	PAB	212.7
90	1210	6	E	2	UNK	6.3	2000	2105	2	E	S&D	DQ	458
90	1215	40	E	2	KH	4.3	2000	2105	3	E	S&D	PAB	137.7
90	1216	38	E	2	UNK	4.8	2000	2110	37	E	S&D	DQ	123
90	1218	16	E	2	UNK	26.7	2000	2110	72	E	S&D	DQ	114.1
90	1223	6	E	2	KH	153	2000	2110	74	E	S&D	DQ	36.7
90	1223	1	E	2	KH	200	2000	2110	33	E	S&D	PAB	149
90	1224	6	E	2	KH	98	2000	2110	34	E	S&D	PAB	161.5
90	1228	3	E	2	KH	1.5	2000	2110	36	E	S&D	PAB	100.8
90	1228	4	E	2	KH	0.9	2000	2110	38	E	S&D	PAB	278
90	1232	4	E	2	KH	193.7	2000	2110	40	E	S&D	PAB	237.5
90	1232	6	E	2	KH	4.6	2000	2110	73	E	S&D	PAB	35.9
90	1234	1	E	2	KH	18.3	2000	2110	319	E	S&D	PAB	432
90	1235	1	E	2	KH	1	2000	2110	320	E	S&D	PAB	263
90	1260	33	E	S&D	KH	102	2000	2110	39	E	S&D	UNK	300
90	1260	34	E	S&D	UNK	219	2000	2110	326	E	S&D	UNK	116.2

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams
2000	2110	328	E	S&D	UNK	252
2000	2111	73	E	S&D	UNK	227.8
2000	2112	66	E	S&D	DQ	39.4
2000	2112	64	E	S&D	KH	284.9
2000	2112	67	E	S&D	KH	36.6
2000	2112	65	E	S&D	PAB	129.2
2000	2113	54	E	S&D	UNK	103.7
2000	2114	63	E	S&D	PAB	217.1
2000	2114	78	E	S&D	UNK	14.2
2000	2115	48	E	S&D	PAB	219.8
2000	2115	49	E	S&D	PAB	280
2000	2115	70	E	S&D	PAB	392
2000	2121	110	E	S&D	DQ	148.5
2000	2121	198	E	S&D	DQ	202
2000	2121	108	E	S&D	PAB	1302
2000	2121	109	E	S&D	PAB	258.8
2000	2121	111	E	S&D	PAB	74.8
2000	2121	112	E	S&D	PAB	475
2000	2121	113	E	S&D	PAB	145.9
2000	2121	114	E	S&D	PAB	213
2000	2121	115	E	S&D	PAB	234.7
2000	2121	116	E	S&D	PAB	188.1
2000	2121	117	E	S&D	PAB	974
2000	2121	118	E	S&D	UNK	363
2000	2123	16	E	S&D	KH	617
2000	2123	33	E	S&D	PAB	107.3
2000	2123	17	E	S&D	UNK	682
2000	2133	1	E	S&D	PAB	140.2
2000	2133	27	E	S&D	UNK	16.3
2000	2133	28	E	S&D	UNK	3.6
2000	2139	147	E	S&D	DQ	20.3
2000	2139	149	E	S&D	DQ	18.1
2000	2139	143	E	S&D	PAB	21.9.5
2000	2139	145	E	S&D	PAB	83.2
2000	2139	151	E	S&D	PAB	388
2000	2139	152	E	S&D	PAB	581
2000	2139	144	E	S&D	UNK	24.8
2000	2139	146	E	S&D	UNK	46.6
2000	2139	148	E	S&D	UNK	57.2
2000	2140	8	E	3A	PAB	102.6
2000	2149	35	E	S&D	PAB	387
2000	2149	36	E	S&D	UNK	254.5
2000	2150	1	E	S&D	PAB	195
2000	2151	70	E	S&D	DQ	11.2
2000	2151	71	E	S&D	PAB	64
2000	2151	72	E	S&D	PAB	53.3
2000	2157	20	E	3B	UNK	139.6
2000	2158	9	E	3B	KH	96.7
2000	2165	35	E	S&D	PAB	104.3
2000	2165	36	E	S&D	PAB	98.2
2000	2165	37	E	S&D	PAB	130.1
2000	2174	315	E	S&D	DQ	121.5
2000	2174	319	E	S&D	DQ	787
2000	2174	317	E	S&D	PAB	1396
2000	2174	318	E	S&D	PAB	2006
2000	2174	320	E	S&D	PAB	549
2000	2174	854	E	S&D	PAB	170.1
2000	2174	911	E	S&D	PAB	1734
2000	2174	912	E	S&D	PAB	153.7
2000	2174	913	E	S&D	PAB	633
2000	2174	914	E	S&D	PAB	888
2000	2174	915	E	S&D	PAB	125.7
2000	2174	916	E	S&D	PAB	198.4
2000	2174	917	E	S&D	PAB	240.1
2000	2174	918	E	S&D	PAB	251
2000	2174	919	E	S&D	PAB	158.5
2000	2174	922	E	S&D	PAB	303
2000	2174	976	E	S&D	PAB	2445
2000	2174	977	E	S&D	PAB	2084
2000	2174	316	E	S&D	UNK	130.9
2000	2174	708	E	S&D	UNK	72.1
2000	2174	910	E	S&D	UNK	85.5
2000	2174	921	E	S&D	UNK	227.8
2000	2174	923	E	S&D	UNK	95.4
2000	2174	924	E	S&D	UNK	266.9
2000	2194	51	E	S&D	UNK	137
2000	2215	23	E	S&D	PAB	321
2000	2226	157	E	S&D	DQ	195.3
2000	2226	173	E	S&D	DQ	31.7
2000	2226	174	E	S&D	PAB	407
2000	2226	175	E	S&D	PAB	105.7
2000	2226	179	E	S&D	PAB	562
2000	2226	180	E	S&D	PAB	1906
2000	2226	177	E	S&D	UNK	40.2
2000	2226	178	E	S&D	UNK	233.1
2000	2227	66	E	S&D	DQ	32
2000	2227	64	E	S&D	PAB	136.7
2000	2227	67	E	S&D	PAB	7.2
2000	2227	374	E	S&D	PAB	171.4
2000	2227	376	E	S&D	PAB	324

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
2000	2227	377	E	S&D	PAB	117		2000	2777	31	E	3C	KH	77.7
2000	2227	63	E	S&D	UNK	3.7		2000	2782	7	E	S&D	PAB	6
2000	2227	375	E	S&D	UNK	72.8		2000	2784	5	E	3C	PAB	258.3
2000	2229	23	E	3B	UNK	42.6		2000	2784	35	E	3C	UNK	162.9
2000	2232	1	E	3B	PAB	130		2000	2789	25	E	3C	DQ	310
2000	2235	1	E	3B	PAB	152		2000	2794	1	E	3C	DQ	804
2000	2312	30	E	3A	DQ	278.5		2000	2795	1	E	3C	UNK	268
2000	2312	31	E	3A	DQ	34.9		2000	2824	21	E	3C	GSS	1265
2000	2338	8	E	3A	PAB	326		2000	2824	22	E	3C	PAB	510
2000	2358	28	E	S&D	DQ	12.4		2000	2824	23	E	3C	PAB	115.6
2000	2358	29	E	S&D	PAB	15.3		2000	2824	24	E	3C	PAB	209
2000	2358	30	E	S&D	PAB	9.8		2000	2825	20	E	3C	GSS	721
2000	2358	27	E	S&D	UNK	265.1		2000	2836	15	E	3C	PAB	279.6
2000	2359	76	E	S&D	KH	48.2		2000	2840	12	E	3C	UNK	17.4
2000	2361	97	E	S&D	KH	142		2000	2853	12	E	3C	PAB	48.3
2000	2362	7	E	S&D	PAB	243.1		2000	2853	13	E	3C	PAB	35.1
2001	2375	13	E	S&D	PAB	408.5		2000	2855	8	E	3C	UNK	202.2
2001	2378	4	E	3C	PAB	1064		2001	2906	2	E	3B	PAB	327.2
2001	2381	14	E	3C	KH	262		2001	2911	11	E	3B	DQ	92.3
2001	2381	15	E	3C	PAB	458.5		2001	2913	157	E	3B	PAB	716.8
2001	2393	1	E	3B	PAB	499		2001	2913	158	E	3B	PAB	50
2001	2416	1	E	S&D	UNK	443.8		2001	2920	3	E	S&D	PAB	22.9
2001	2416	2	E	S&D	UNK	51.9		2001	2920	4	E	S&D	PAB	941.6
2000	2501	2	E	S&D	UNK	309		2001	2921	6	E	S&D	PAB	244.2
2000	2502	2	E	S&D	DQ	560		2001	2939	43	E	3B	UNK	253.1
2000	2502	4	E	S&D	GSS	241		2001	2940	1	E	3B	PAB	3000
2000	2502	1	E	S&D	PAB	265.5		2001	2940	2	E	3B	PAB	343.8
2000	2502	3	E	S&D	PAB	139.7		2001	2944	37	E	3B	PAB	79.6
2000	2717	37	E	S&D	DQ	79.6		2001	2944	38	E	3B	PAB	80.2
2000	2719	26	E	S&D	UNK	37.9		90	3000	8	n/a	n/a	DQ	450
2000	2720	21	E	S&D	UNK	52.9		90	3001	10	E	S&D	PAB	275
2000	2725	17	E	3C	DQ	21.6		90	3007	2	E	S&D	DQ	60.9
2000	2726	1	E	3C	PAB	497		90	3011	52	E	S&D	PAB	40.7
2000	2726	2	E	3C	UNK	240.5		90	3011	53	E	S&D	PAB	575.2
2000	2727	19	E	3C	UNK	59.8		90	3011	51	E	S&D	UNK	500
2000	2727	21	E	3C	UNK	81.5		90	3014	15	E	S&D	PAB	745.5
2000	2728	1	E	3C	DQ	445		90	3022	31	E	S&D	UNK	180.5
2000	2728	2	E	3C	PAB	150		90	3025	23	E	S&D	PAB	523.3
2000	2753	21	E	3C	DQ	62.9		90	3025	24	E	S&D	PAB	174.8
2000	2755	23	E	3C	PAB	30.8		90	3025	25	E	S&D	UNK	131.8
2000	2755	25	E	3C	UNK	100		90	3026	36	E	S&D	UNK	72.8
2000	2758	18	E	3C	UNK	562		90	3028	82	E	S&D	DQ	72.8
2000	2762	25	E	3C	PAB	222.4		90	3028	16	E	S&D	UNK	1310
2000	2763	28	E	3C	UNK	92.8		90	3028	64	E	S&D	UNK	164.6
2000	2776	39	E	3C	DQ	374		90	3037	46	E	S&D	PAB	160.4

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams	year	lot	record	location	context	material	grams
90	3037	47	E	S&D	PAB	67.4	90	3221	21	E	S&D	DQ	160.6
90	3038	8	E	3B	UNK	29.2	90	3221	4	E	S&D	PAB	398
90	3040	31	E	S&D	PAB	1253	90	3222	27	E	3C	PAB	1358
90	3040	32	E	S&D	PAB	834	90	3222	57	E	3C	PAB	378.5
90	3040	33	E	S&D	PAB	672	90	3222	26	E	3C	UNK	137
90	3040	34	E	S&D	PAB	1583	90	3222	55	E	3C	UNK	81.8
90	3040	35	E	S&D	PAB	625	90	3223	2	E	3C	PAB	124
90	3040	2	E	S&D	UNK	271.9	90	3223	12	E	3C	UNK	106
90	3042	20	E	S&D	GSS	179.5	90	3230	3	E	3C	DQ	239.1
90	3042	3	E	S&D	PAB	438	90	3240	6	E	3C	PAB	259.5
90	3043	1	E	S&D	PAB	404.5	90	3241	3	E	3C	PAB	366.5
90	3063	6	E	3B	GSS	60.8	90	3247	46	E	S&D	GSS	343.5
90	3064	17	E	3B	DQ	108.8	90	3247	43	E	S&D	PAB	290.2
90	3068	3	E	S&D	GSS	242.1	90	3247	44	E	S&D	PAB	92.2
90	3068	82	E	S&D	UNK	191.2	90	3247	45	E	S&D	PAB	127.7
90	3079	6	E	3B	PAB	138.3	90	3247	1	E	S&D	UNK	254
90	3089	13	E	3A	PAB	36.7	90	3253	22	E	3B	GSS	918
90	3091	2	E	3C	UNK	51.6	90	3253	17	E	3B	PAB	411
90	3094	3	E	3C	GSS	924.5	90	3253	18	E	3B	PAB	229.4
90	3094	2	E	3C	PAB	170.2	90	3253	19	E	3B	PAB	717.7
90	3094	2	E	3C	UNK	150.9	90	3253	20	E	3B	PAB	34.1
90	3101	11	E	S&D	PAB	167	90	3253	16	E	3B	UNK	54
90	3101	12	E	S&D	PAB	94.5	90	3265	4	E	S&D	PAB	68.7
90	3104	1	E	S&D	PAB	195.7	90	3266	3	E	3B	PAB	375.5
90	3104	27	E	S&D	UNK	155.5	90	3266	4	E	3B	UNK	103.6
90	3106	18	E	3C	DQ	85.5	90	3277	2	E	3A	PAB	109
90	3106	4	E	3C	UNK	324	90	3281	16	E	3A	UNK	154.4
90	3107	2	E	3C	PAB	168.8	90	3289	1	E	3A	PAB	892
90	3107	7	E	3C	UNK	132.8	90	3290	25	E	S&D	PAB	9.5
90	3109	15	E	3C	UNK	17.5	90	3290	24	E	S&D	UNK	171.1
90	3111	2	E	3C	GSS	477.7	90	3291	6	E	3C	PAB	1252
90	3113	1	E	3C	KH	104.7	2000	3311	1	E	3C	UNK	248.5
90	3115	62	E	3C	PAB	85.2	2000	3315	1	E	3C	UNK	3761
90	3117	1	E	3C	PAB	4200	90	3400	3	E	3B	UNK	137.5
90	3132	8	E	3C	UNK	40	90	3406	15	E	3B	PAB	167.2
90	3138	3	E	3B	PAB	2000	90	3430	2	E	3C	UNK	183.8
90	3151	24	E	3B	PAB	322.3	93	3501	6	E	S&D	UNK	124.8
90	3173	12	E	S&D	SR	75.7	93	3502	42	E	S&D	PAB	33.4
90	3186	14	E	3A	KH	20.6	93	3504	19	E	3C	PAB	50.9
90	3188	29	E	S&D	PAB	102.7	93	3505	16	E	S&D	DQ	655
90	3188	39	E	S&D	PAB	988.5	93	3506	62	E	S&D	DQ	96.8
90	3188	28	E	S&D	UNK	181	93	3506	61	E	S&D	PAB	270.9
90	3191	19	E	S&D	PAB	122	93	3506	67	E	S&D	PAB	127
90	3191	20	E	S&D	UNK	164.6	93	3511	14	E	S&D	PAB	92
90	3221	5	E	S&D	DQ	244.8	93	3515	8	E	3C	KH	2

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
93	3516	36	E	S&D	PAB	100		93	3556	10	E	3C	DQ	26.2
93	3517	5	E	S&D	PAB	66.3		93	3556	8	E	3C	UNK	23.5
93	3527	1	E	3C	PAB	8200		93	3557	7	E	S&D	DQ	73.8
93	3527	2	E	3C	UNK	519		93	3559	2	E	3C	GSS	6.5
93	3527	3	E	3C	UNK	359.5		93	3563	15	E	3C	PAB	79.7
93	3527	4	E	3C	UNK	117		93	3564	2	E	3C	UNK	39.6
93	3530	37	E	S&D	DQ	75.4		93	3565	16	E	3C	DQ	9.5
93	3530	38	E	S&D	DQ	41.5		93	3567	3	E	3C	DQ	18.9
93	3530	48	E	S&D	DQ	19.1		93	3574	9	E	3C	PAB	19.2
93	3530	51	E	S&D	DQ	1053		93	3575	10	E	3C	PAB	18.4
93	3530	52	E	S&D	PAB	55.3		93	3575	24	E	3C	PAB	6.9
93	3530	39	E	S&D	SR	24.2		93	3596	23	E	3C	PAB	2
93	3532	97	E	S&D	DQ	247.5		93	3601	27	E	3B	KH	105.6
93	3532	98	E	S&D	DQ	194.8		93	3602	19	E	3B	PAB	232.9
93	3532	99	E	S&D	DQ	103.3		93	3604	4	E	3B	UNK	24.7
93	3532	100	E	S&D	UNK	129.8		93	3606	46	E	3B	PAB	5.6
93	3533	94	E	S&D	DQ	35.9		93	3614	6	E	2	PAB	149.6
93	3533	95	E	S&D	DQ	8.8		93	3623	1	E	3C	UNK	73.5
93	3533	96	E	S&D	DQ	3.1		93	3641	12	E	3B	KH	76
93	3533	90	E	S&D	PAB	52.2		93	3644	7	E	3B	UNK	17.6
93	3533	91	E	S&D	PAB	25.1		93	3645	67	E	3B	KH	25.4
93	3533	100	E	S&D	PAB	18.7		93	3649	9	E	3A	KH	156.6
93	3533	101	E	S&D	PAB	53.8		93	3700	40	E	S&D	DQ	236.5
93	3534	15	E	S&D	DQ	11.4		93	3700	41	E	S&D	UNK	36.4
93	3534	29	E	S&D	UNK	7.4		93	3704	11	E	3C	DQ	189
93	3535	30	E	S&D	PAB	228		93	3705	5	E	S&D	DQ	52.6
93	3535	50	E	S&D	UNK	248.3		93	3705	4	E	S&D	UNK	365
93	3536	6	E	S&D	UNK	95.9		93	3707	13	E	3C	PAB	33.6
93	3536	7	E	S&D	UNK	53.3		93	3709	21	E	S&D	DQ	65.5
93	3537	37	E	S&D	DQ	57.4		93	3709	22	E	S&D	DQ	72.2
93	3537	38	E	S&D	DQ	171		93	3709	15	E	S&D	PAB	95.8
93	3537	39	E	S&D	DQ	111.2		93	3710	14	E	3C	DQ	84.5
93	3537	35	E	S&D	PAB	132.6		93	3710	28	E	3C	DQ	45.8
93	3537	36	E	S&D	UNK	90.1		93	3710	27	E	3C	PAB	63
93	3538	43	E	3C	PAB	39.4		93	3710	30	E	3C	PAB	29.3
93	3539	8	E	3C	DQ	98.1		93	3710	29	E	3C	UNK	7.7
93	3541	51	E	3C	PAB	608.5		93	3714	4	E	3C	PAB	439
93	3541	52	E	3C	PAB	73		93	3716	11	E	3C	PAB	19.5
93	3544	27	E	3C	PAB	75.6		93	3739	36	E	S&D	DQ	65.4
93	3545	18	E	3C	PAB	912.5		93	3802	7	E	S&D	DQ	88
93	3548	11	E	3C	PAB	33.9		93	3802	9	E	S&D	DQ	52.4
93	3552	23	E	S&D	PAB	67.9		93	3802	6	E	S&D	PAB	222.4
93	3555	31	E	S&D	DQ	914		93	3802	8	E	S&D	UNK	131.5
93	3555	32	E	S&D	PAB	103		93	3803	37	E	S&D	DQ	214.1
93	3556	9	E	3C	DQ	108.7		93	3803	35	E	S&D	PAB	245.5

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
93	3803	101	E	S&D	UNK	46.5		93	3864	9	E	3C	DQ	116.7
93	3804	57	E	S&D	PAB	1076		93	3864	10	E	3C	DQ	132.4
93	3804	58	E	S&D	PAB	124.5		93	3864	21	E	3C	PAB	191.7
93	3804	23	E	S&D	UNK	46.3		93	3864	23	E	3C	PAB	122.6
93	3804	54	E	S&D	UNK	63.7		93	3865	37	E	3C	GSS	107
93	3804	55	E	S&D	UNK	29.8		93	3865	29	E	3C	PAB	104.7
93	3806	71	E	3C	UNK	96.8		93	3865	44	E	3C	PAB	106.8
93	3809	13	E	3C	DQ	98.9		93	3865	4	E	3C	UNK	165.9
93	3811	4	E	3C	DQ	144.7		93	3866	8	E	3C	PAB	31.1
93	3812	10	E	3C	UNK	74.6		93	3866	32	E	3C	UNK	123.6
93	3813	3	E	3C	UNK	43.2		93	3866	40	E	3C	UNK	10.5
93	3814	8	E	3C	UNK	126.8		93	3866	41	E	3C	UNK	91.9
93	3829	3	E	S&D	GSS	1486		93	3867	48	E	3C	UNK	19.3
93	3830	1	E	S&D	DQ	84.7		93	3868	11	E	3C	DQ	63.7
93	3830	2	E	S&D	DQ	40.1		93	3868	12	E	3C	DQ	66.2
93	3831	7	E	S&D	DQ	718.3		93	3869	47	E	3C	DQ	30.4
93	3831	8	E	S&D	DQ	858.3		93	3869	52	E	3C	DQ	34.2
93	3832	8	E	S&D	PAB	39.7		93	3869	5	E	3C	UNK	447.4
93	3833	11	E	S&D	UNK	118.9		93	3873	12	E	S&D	DQ	8.5
93	3834	6	E	S&D	DQ	35.9		93	3876	6	E	S&D	PAB	252.6
93	3834	7	E	S&D	PAB	170		94	3879	8	E	S&D	DQ	91.3
93	3834	8	E	S&D	UNK	77.6		94	3879	9	E	S&D	DQ	4.5
93	3835	8	E	S&D	DQ	69.4		94	3879	23	E	S&D	DQ	19.6
93	3835	10	E	S&D	PAB	263.4		94	3879	21	E	S&D	KH	59.4
93	3836	25	E	S&D	DQ	52.1		94	3879	22	E	S&D	PAB	22.7
93	3836	29	E	S&D	DQ	205.3		93	3887	10	E	3C	GSS	130.7
93	3836	4	E	S&D	PAB	21.2		93	3888	22	E	3C	UNK	23.7
93	3836	26	E	S&D	PAB	56.9		93	3890	15	E	3C	DQ	112.6
93	3836	30	E	S&D	PAB	161.8		93	3891	20	E	3C	DQ	119.8
93	3836	31	E	S&D	PAB	176.6		93	3891	24	E	3C	DQ	95
93	3836	24	E	S&D	UNK	52		93	3891	25	E	3C	GSS	221.1
93	3838	12	E	S&D	PAB	416.7		93	3892	14	E	3C	DQ	25.5
93	3839	33	E	S&D	DQ	510		93	3892	57	E	3C	DQ	583.5
93	3839	35	E	S&D	DQ	17.6		93	3892	59	E	3C	DQ	18.5
93	3839	69	E	S&D	DQ	211.8		93	3892	60	E	3C	DQ	13.4
93	3839	37	E	S&D	PAB	62.3		93	3892	61	E	3C	DQ	60.6
93	3839	38	E	S&D	PAB	117.9		93	3892	62	E	3C	DQ	34.7
93	3839	36	E	S&D	UNK	53.2		93	3892	63	E	3C	DQ	77.9
93	3840	1	E	3C	DQ	76.1		93	3892	64	E	3C	DQ	47.5
93	3841	17	E	S&D	DQ	76.5		93	3892	74	E	3C	DQ	67.4
93	3860	2	E	S&D	DQ	22		93	3892	13	E	3C	PAB	392.4
93	3861	2	E	S&D	DQ	37.6		93	3892	66	E	3C	PAB	14.6
93	3862	7	E	S&D	PAB	40.3		93	3892	67	E	3C	PAB	82.5
93	3863	20	E	S&D	DQ	44.4		93	3892	75	E	3C	PAB	237.6
93	3863	19	E	S&D	UNK	56.8		93	3892	65	E	3C	UNK	53.9

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
93	3892	73	E	3C	UNK	55.2		93	4051	12	ET	S&D	PAB	223
94	3899	3	E	S&D	UNK	143.3		93	4065	73	ET	3B	KH	11.7
94	3899	4	E	S&D	UNK	130.5		93	4065	71	ET	3B	PAB	928.5
94	3903	29	E	S&D	PAB	21.2		93	4065	72	ET	3B	PAB	46.4
94	3903	34	E	S&D	PAB	117.2		93	4069	9	ET	3B	PAB	296.3
94	3904	25	E	3C	PAB	204.6		93	4069	10	ET	3B	PAB	310.2
94	3904	26	E	3C	PAB	109.6		93	4074	33	ET	3C	PAB	399
94	3904	29	E	3C	UNK	74.5		93	4090	14	ET	3B	PAB	28.1
94	3904	43	E	3C	UNK	117.4		93	4098	16	ET	3B	PAB	2800
94	3912	7	E	3C	UNK	40		93	4099	2	ET	3B	KH	64.4
94	3917	15	E	3C	PAB	66.9		93	4100	3	ET	3C	UNK	164
94	3918	2	E	3C	DQ	99.1		93	4100	13	ET	3C	UNK	29.3
94	3921	4	E	3C	PAB	121.5		93	4106	41	ET	3C	GSS	43.1
94	3922	4	E	3C	UNK	120.4		93	4111	10	ET	3C	UNK	120
94	3924	19	E	3C	DQ	912.5		93	4128	7	ET	3B	PAB	149.6
94	3931	6	E	3C	PAB	94.9		93	4161	22	ET	3B	KH	64.8
94	3931	8	E	3C	PAB	11.3		93	4193	38	ET	3C	GSS	18.1
94	3935	25	E	3C	DQ	115.2		93	4200	23	ET	S&D	UNK	216.3
94	3935	26	E	3C	DQ	62.7		93	4213	1	ET	S&D	PAB	1219
94	3935	27	E	3C	DQ	46.4		93	4250	24	ET	3B	PAB	972.5
94	3935	29	E	3C	DQ	19.7		93	4255	5	ET	S&D	PAB	138
94	3935	28	E	3C	PAB	27.8		93	4302	19	E	3B	PAB	22
94	3935	30	E	3C	PAB	15.9		93	4314	2	ET	S&D	PAB	161.3
94	3940	2	E	S&D	DQ	47		93	4325	1	E	2	PAB	470
94	3942	1	E	3C	DQ	602.3		93	4330	4	E	3B	PAB	309
94	3942	2	E	3C	DQ	936.1		93	4330	14	E	3B	PAB	199
94	3946	61	E	3C	DQ	108		93	4335	10	E	2	PAB	1178
94	3946	62	E	3C	PAB	92		93	4341	5	E	2	UNK	6.1
94	3947	19	E	3C	UNK	600		95	4411	18	ET	S&D	UNK	164.2
94	3951	29	Tr.21	S&D	PAB	185.9		95	4415	15	ET	S&D	PAB	260.6
94	3965	32	Tr.21	3B	PAB	108		95	4415	16	ET	S&D	PAB	94.3
94	3966	6	Tr.21	3B	PAB	632.3		95	4416	34	ET	3C	PAB	536.5
94	3984	59	E	S&D	UNK	136.5		95	4423	78	ET	S&D	GSS	274.2
94	3985	41	E	3C	DQ	52.5		95	4423	32	ET	S&D	PAB	33.1
94	3985	42	E	3C	DQ	18		95	4427	14	ET	S&D	UNK	256.7
94	3987	36	E	3C	PAB	149		95	4433	31	ET	S&D	UNK	175.1
94	3989	11	E	3C	PAB	75.9		95	4442	5	ET	3C	PAB	150.4
94	3998	11	E	3C	PAB	145.8		95	4445	381	ET	S&D	PAB	182.2
93	4004	8	ET	S&D	UNK	28.9		95	4461	3	ET	3C	PAB	423.9
93	4016	10	ET	S&D	PAB	750		95	4463	2	ET	3C	PAB	421.1
93	4016	9	ET	S&D	UNK	283.5		95	4463	3	ET	3C	PAB	773.9
93	4030	6	ET	S&D	PAB	206.1		95	4463	4	ET	3C	PAB	527.6
93	4041	1	ET	S&D	UNK	57.6		95	4463	5	ET	3C	PAB	1722
93	4046	1	ET	3B	PAB	559.9		95	4466	45	ET	S&D	PAB	626.6
93	4051	2	ET	S&D	PAB	419.9		95	4466	65	ET	S&D	PAB	23

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
95	4466	66	ET	S&D	PAB	7.1		95	4687	1	ET	3B	UNK	438.7
95	4468	1	E	3B	PAB	436		94	4700	4	ET	S&D	DQ	27.9
95	4484	1	E	3A	PAB	374		94	4700	6	ET	S&D	DQ	131.5
95	4545	9	ET	3B	UNK	68		94	4700	7	ET	S&D	DQ	70.6
95	4565	2	ET	3B	PAB	2980		94	4700	8	ET	S&D	DQ	15.4
95	4572	1	ET	3B	UNK	717.4		94	4700	10	ET	S&D	DQ	34.8
95	4587	1	ET	3B	PAB	224.2		94	4700	5	ET	S&D	PAB	133.9
95	4606	35	ET	3B	PAB	312.3		94	4700	9	ET	S&D	UNK	15.1
95	4607	47	ET	S&D	DQ	242		94	4701	6	ET	S&D	DQ	40.9
95	4607	7	ET	S&D	KH	306		94	4701	7	ET	S&D	DQ	37.8
95	4609	208	ET	S&D	DQ	261.7		94	4702	31	ET	S&D	DQ	29.8
95	4609	40	ET	S&D	PAB	794.3		94	4702	32	ET	S&D	DQ	43.8
95	4609	41	ET	S&D	PAB	90		94	4702	33	ET	S&D	DQ	19.6
95	4609	44	ET	S&D	PAB	659.5		94	4702	34	ET	S&D	DQ	31.4
95	4609	45	ET	S&D	PAB	594.2		94	4702	12	ET	S&D	PAB	30.5
95	4609	124	ET	S&D	PAB	173		94	4702	30	ET	S&D	PAB	143.5
95	4609	181	ET	S&D	PAB	112.5		94	4702	11	ET	S&D	UNK	92.9
95	4611	14	ET	3B	PAB	16		94	4704	47	ET	3C	DQ	22.6
95	4613	3	ET	3B	PAB	336.5		94	4704	30	ET	3C	GSS	61.5
95	4613	43	ET	3B	PAB	185.2		94	4707	10	ET	S&D	DQ	394.4
95	4614	44	ET	3B	DQ	201.3		94	4707	17	ET	S&D	PAB	7
95	4614	1	ET	3B	PAB	190.8		94	4707	33	ET	S&D	UNK	21.7
95	4614	42	ET	3B	PAB	158.2		94	4712	8	ET	3C	UNK	200.5
95	4614	43	ET	3B	PAB	154.7		94	4714	10	ET	3C	PAB	44.4
95	4614	46	ET	3B	PAB	138.8		95	4716	4	ET	S&D	DQ	1577
95	4614	40	ET	3B	UNK	180		95	4716	3	ET	S&D	PAB	71.4
95	4615	2	ET	3C	PAB	153.5		95	4719	84	ET	3C	DQ	13
95	4623	38	ET	S&D	DQ	291.1		95	4719	85	ET	3C	DQ	10
95	4623	114	ET	S&D	DQ	58.5		95	4719	171	ET	3C	PAB	106
95	4623	23	ET	S&D	PAB	345.9		95	4719	172	ET	3C	PAB	148.7
95	4623	113	ET	S&D	PAB	375.5		95	4719	82	ET	3C	UNK	31.99
95	4623	115	ET	S&D	PAB	30		95	4719	83	ET	3C	UNK	10.5
95	4623	119	ET	S&D	PAB	418.3		95	4719	113	ET	3C	UNK	127
95	4624	5	ET	3C	PAB	63.7		95	4719	114	ET	3C	UNK	101.6
95	4647	66	ET	S&D	DQ	77		95	4720	112	ET	3C	DQ	740.5
95	4647	19	ET	S&D	PAB	170.8		95	4721	4	ET	3C	DQ	224.9
95	4651	3	ET	S&D	PAB	80.5		95	4721	5	ET	3C	DQ	177.6
95	4654	18	ET	3B	PAB	21.9		95	4721	132	ET	3C	DQ	57.2
95	4665	1	ET	3B	PAB	992.8		95	4721	3	ET	3C	UNK	188.2
95	4667	1	ET	S&D	PAB	1419		95	4721	6	ET	3C	UNK	208
95	4667	14	ET	S&D	PAB	213.7		95	4721	133	ET	3C	UNK	54.5
95	4669	4	ET	3B	DQ	1160		95	4723	108	ET	3C	PAB	285.6
95	4669	6	ET	3B	PAB	288.3		95	4723	111	ET	3C	PAB	134
95	4681	11	ET	3B	PAB	362.9		95	4724	15	ET	3C	PAB	31.3
95	4687	2	ET	3B	GSS	300.2		95	4724	86	ET	3C	PAB	1012

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams
95	4725	6	ET	3C	PAB	778.4
95	4726	110	ET	3C	DQ	562.3
95	4726	112	ET	3C	DQ	6
95	4726	212	ET	3C	DQ	176
95	4726	215	ET	3C	GSS	10.5
95	4726	113	ET	3C	PAB	394
95	4726	213	ET	3C	UNK	344.6
95	4726	214	ET	3C	UNK	3.98
95	4728	214	ET	3C	GSS	255.5
95	4731	6	ET	3C	DQ	13.5
95	4733	52	ET	3C	DQ	52
95	4733	23	ET	3C	GSS	161.5
95	4733	22	ET	3C	UNK	110
95	4734	4	ET	3C	GSS	315
95	4734	40	ET	3C	PAB	185
95	4737	2	ET	3C	PAB	467.5
95	4738	7	ET	3C	PAB	370
95	4738	5	ET	3C	UNK	23.5
95	4740	2	ET	3C	PAB	664.5
95	4741	1	ET	3C	DQ	235
95	4743	1	ET	3C	DQ	278
95	4751	5	ET	3C	DQ	88.5
95	4751	19	ET	3C	PAB	44.5
95	4752	8	ET	3C	DQ	602.5
94	4803	1	ET	S&D	DQ	478.6
94	4803	2	ET	S&D	DQ	647.3
94	4805	3	ET	S&D	DQ	257.1
94	4810	251	ET	3C	PAB	13.5
94	4819	9	ET	S&D	DQ	540.2
94	4819	7	ET	S&D	UNK	492.4
94	4824	6	ET	3C	KH	421
94	4857	6	ET	S&D	PAB	102.7
94	4860	25	ET	S&D	UNK	354
94	4860	27	ET	S&D	UNK	86.8
95	4910	40	ET	3C	DQ	11.9
95	4910	41	ET	3C	DQ	23.9
95	4910	42	ET	3C	DQ	19
95	4910	39	ET	3C	UNK	3.8
95	4911	16	ET	3C	PAB	198
95	4911	113	ET	3C	PAB	592
95	4913	10	ET	3C	UNK	102
95	4913	11	ET	3C	UNK	18.3
95	4916	51	ET	3C	DQ	55.2
95	4916	52	ET	3C	PAB	175.8
95	4916	50	ET	3C	UNK	18.7
95	4916	139	ET	3C	UNK	48.2
95	4917	9	ET	3C	DQ	83.4
95	4917	20	ET	3C	GSS	66.8
95	4917	10	ET	3C	UNK	136.1
95	4918	5	ET	3C	PAB	244.9
95	4918	12	ET	3C	PAB	54.2
95	4919	13	ET	3C	DQ	42.4
95	4919	14	ET	3C	DQ	671.6
95	4919	15	ET	3C	PAB	143.1
95	4919	16	ET	3C	PAB	266
95	4919	26	ET	3C	PAB	79
95	4920	3	ET	3C	PAB	19.3
95	4921	25	ET	3C	DQ	8.9
95	4921	26	ET	3C	DQ	31.6
95	4921	31	ET	3C	PAB	38.9
95	4921	139	ET	3C	PAB	108.7
95	4922	4	ET	3C	PAB	318.5
95	4922	18	ET	3C	PAB	57
95	4922	75	ET	3C	PAB	2500
95	4923	101	ET	3C	UNK	17
95	4926	215	ET	3C	PAB	539
95	4933	16	ET	S&D	PAB	88
95	4934	107	ET	S&D	UNK	91
95	4935	20	ET	S&D	DQ	27
95	4935	44	ET	S&D	UNK	46.3
95	4936	19	ET	3C	UNK	75.9
95	4940	107	ET	3C	DQ	42.6
95	4940	75	ET	3C	PAB	184.9
95	4940	109	ET	3C	UNK	309.9
95	4941	6	ET	3C	DQ	246.6
95	4942	4	ET	S&D	PAB	190.3
95	4942	3	ET	S&D	UNK	916.1
95	4943	34	ET	S&D	DQ	347.1
95	4943	51	ET	S&D	DQ	33.5
95	4943	12	ET	S&D	GSS	60.5
95	4943	57	ET	S&D	PAB	57.4
95	4945	35	ET	3C	PAB	533.6
95	4949	1	ET	S&D	UNK	8.3
95	4949	2	ET	S&D	UNK	87.2
95	4950	1	ET	3C	PAB	142.7
95	4952	45	ET	3C	DQ	104.3
95	4953	171	ET	3C	KH	126.7
95	4953	208	ET	3C	UNK	2.5
95	4954	2	ET	3C	PAB	77.3
95	4960	28	ET	S&D	DQ	149.8

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
95	4960	23	ET	S&D	UNK	12.8		94	5044	11	MS	S&D	DQ	28.3
95	4961	4	ET	3C	GSS	280.7		94	5044	9	MS	S&D	PAB	73.4
95	4961	2	ET	3C	PAB	189		94	5044	10	MS	S&D	UNK	138.8
95	4961	3	ET	3C	PAB	335		94	5046	50	MS	3C	DQ	29
95	4961	5	ET	3C	PAB	1111		94	5051	1	MS	S&D	UNK	500
95	4962	124	ET	S&D	GSS	11.3		94	5063	78	MS	3C	UNK	17.1
95	4963	6	ET	3C	DQ	492		94	5070	1	MS	3C	DQ	30.2
95	4963	38	ET	3C	DQ	304.7		94	5076	41	MS	3C	DQ	16.5
95	4970	54	ET	3C	DQ	134.2		94	5076	40	MS	3C	UNK	161.1
95	4973	4	ET	3C	DQ	29.3		94	5076	42	MS	3C	UNK	179.7
95	4973	15	ET	3C	DQ	338.5		94	5084	3	MS	3C	PAB	234
95	4973	3	ET	3C	UNK	58.2		94	5101	1	E	3C	PAB	324
95	4974	86	ET	3C	UNK	1435		94	5101	29	E	3C	UNK	527.5
95	4976	1	ET	3C	PAB	62.9		95	5142	21	E	S&D	PAB	679.8
95	4978	42	ET	3C	PAB	533.4		95	5144	12	E	3C	DQ	105.6
95	4980	6	ET	S&D	PAB	300		95	5144	166	E	3C	DQ	745.2
95	4980	7	ET	S&D	UNK	130.5		95	5144	11	E	3C	UNK	219.2
95	4980	8	ET	S&D	UNK	1125		95	5145	20	E	3C	DQ	431.1
95	4981	59	ET	S&D	GSS	128.4		95	5145	96	E	3C	DQ	177.5
95	4981	38	ET	S&D	PAB	468.3		95	5145	71	E	3C	KH	311.7
95	4981	39	ET	S&D	PAB	117.5		95	5145	62	E	3C	PAB	567.4
95	4981	40	ET	S&D	PAB	234.7		95	5145	63	E	3C	UNK	63.4
95	4981	60	ET	S&D	PAB	388.7		95	5145	97	E	3C	UNK	62.9
95	4981	66	ET	S&D	UNK	77.5		95	5146	62	E	3C	DQ	54.2
95	4982	102	ET	S&D	DQ	76.6		95	5146	95	E	3C	GSS	3000
95	4982	2	ET	S&D	PAB	507.3		95	5146	60	E	3C	UNK	233
95	4982	122	ET	S&D	PAB	60.6		95	5149	167	E	S&D	DQ	118.6
95	4982	123	ET	S&D	UNK	22.5		95	5149	168	E	S&D	PAB	276
95	4986	40	ET	S&D	KH	201.7		95	5150	32	E	3C	DQ	83.3
95	4986	37	ET	S&D	PAB	447		95	5150	33	E	3C	DQ	34.4
95	4986	1	ET	S&D	UNK	21.9		95	5150	1	E	3C	PAB	186.5
95	4988	44	ET	3C	PAB	4988		95	5151	1	E	3C	DQ	196.2
95	4989	91	ET	3C	DQ	45.1		95	5152	23	E	3C	KH	602.2
95	4989	4	ET	3C	GSS	397.9		95	5153	3	E	3C	DQ	37
95	4989	47	ET	3C	PAB	321		95	5153	2	E	3C	UNK	323.3
95	4989	48	ET	3C	PAB	252.9		95	5153	4	E	3C	UNK	49.6
95	4991	2	ET	3C	DQ	106		95	5171	1	E	3C	PAB	45
95	4991	1	ET	3C	PAB	104.8		95	5175	4	E	3C	PAB	329.9
95	4992	3	ET	3C	GSS	644.2		95	5176	1	E	3C	PAB	312.9
93	5024	23	MS	3C	UNK	335.8		95	5181	1	E	3C	DQ	545.4
93	5030	32	MS	3C	GSS	307.7		95	5181	2	E	3C	UNK	203.1
94	5039	13	MS	3C	PAB	159.7		95	5184	24	E	3C	PAB	255
94	5039	15	MS	3C	UNK	225		95	5184	3	E	3C	UNK	70
94	5040	17	MS	S&D	PAB	99.8		95	5188	9	E	3C	UNK	1133
94	5042	33	MS	3C	DQ	138.3		95	5195	5	E	3C	PAB	282

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
94	5200	17	MS	S&D	PAB	111.5		95	5711	30	ET	3C	KH	9.2
94	5200	18	MS	S&D	PAB	86.5		95	5711	31	ET	3C	KH	6.6
94	5200	19	MS	S&D	PAB	20.8		95	5711	33	ET	3C	KH	34
94	5202	5	MS	S&D	DQ	163.6		95	5712	79	ET	S&D	UNK	366.1
94	5204	4	MS	S&D	UNK	34.3		95	5713	118	ET	S&D	DQ	240
94	5207	1	MS	S&D	DQ	168		95	5713	70	ET	S&D	GSS	193.6
94	5251	31	ET	S&D	DQ	60.5		95	5714	11	ET	3C	DQ	16
94	5251	32	ET	S&D	PAB	29		95	5718	58	ET	S&D	UNK	64
94	5344	1	ET	3B	UNK	5500		95	5720	7	ET	3C	UNK	75.9
94	5406	6	ET	S&D	PAB	732.9		95	5720	50	ET	3C	UNK	56.3
94	5501	28	ET	3B	DQ	446.6		95	5723	10	ET	3C	DQ	129
94	5502	61	ET	3B	GSS	279.7		95	5724	49	ET	3C	DQ	143.8
94	5505	1	ET	3B	PAB	288.1		95	5726	80	ET	3C	DQ	34.1
95	5517	8	ET	3B	PAB	62.7		95	5726	15	ET	3C	PAB	797.1
95	5526	10	ET	3B	GSS	802		95	5728	58	ET	3C	DQ	34.1
95	5602	13	ET	S&D	DQ	234.6		95	5728	59	ET	3C	DQ	14
95	5602	12	ET	S&D	PAB	331.1		95	5728	10	ET	3C	KH	87.4
95	5603	34	ET	S&D	DQ	34.8		95	5729	220	ET	3C	DQ	90.5
95	5604	15	ET	S&D	UNK	34.2		95	5729	74	ET	3C	PAB	193
95	5606	22	ET	S&D	PAB	20.6		95	5729	78	ET	3C	PAB	82
95	5607	18	ET	S&D	PAB	210.7		95	5732	23	ET	3C	DQ	193.8
95	5614	21	ET	S&D	PAB	58.7		95	5735	74	ET	S&D	PAB	444
95	5614	22	ET	S&D	PAB	1052		95	5735	75	ET	S&D	UNK	278
95	5616	1	ET	3B	PAB	244.3		95	5737	21	ET	3C	DQ	33
95	5625	4	ET	3B	PAB	126.2		95	5740	23	ET	3C	DQ	104.3
95	5625	21	ET	3B	PAB	448.3		95	5740	24	ET	3C	PAB	359
95	5625	22	ET	3B	PAB	405.2		95	5741	45	ET	3C	DQ	71
95	5629	8	ET	S&D	PAB	318		95	5741	46	ET	3C	DQ	9
95	5631	18	ET	3B	PAB	431.1		95	5741	47	ET	3C	GSS	116
95	5669	8	ET	3B	DQ	108.7		95	5741	49	ET	3C	PAB	150
95	5684	31	ET	3B	UNK	181		95	5741	50	ET	3C	UNK	586
95	5685	13	ET	3B	PAB	816.7		95	5743	13	ET	3C	DQ	135.6
95	5702	17	ET	S&D	DQ	5.4		95	5745	16	ET	S&D	DQ	135
95	5702	68	ET	S&D	DQ	715.8		95	5745	1	ET	S&D	UNK	144
95	5702	4	ET	S&D	UNK	6.1		95	5745	3	ET	S&D	UNK	170
95	5709	101	ET	S&D	DQ	188.8		95	5745	17	ET	S&D	UNK	105.2
95	5709	112	ET	S&D	DQ	90.4		95	5746	89	ET	3C	DQ	23
95	5709	100	ET	S&D	GSS	490.7		95	5746	88	ET	3C	UNK	51
95	5709	102	ET	S&D	UNK	443.7		95	5747	12	ET	3C	DQ	159
95	5709	113	ET	S&D	UNK	623		95	5749	10	ET	3C	DQ	821.5
95	5710	77	ET	S&D	DQ	19.5		95	5749	11	ET	3C	DQ	121.3
95	5710	78	ET	S&D	DQ	6.7		95	5749	12	ET	3C	DQ	39.4
95	5710	79	ET	S&D	PAB	166		95	5750	32	ET	3C	DQ	634.8
95	5711	32	ET	3C	DQ	4		95	5750	1	ET	3C	KH	105.3
95	5711	29	ET	3C	KH	9		95	5751	30	ET	3C	DQ	86.1

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
95	5751	98	ET	3C	UNK	83.7		94	6009	1	F	S&D	DQ	338.3
95	5753	56	ET	3C	DQ	18.3		96	6199	1	n/a	n/a	GSS	152.1
95	5753	57	ET	3C	DQ	61		96	6201	1	ET	S&D	DQ	1741
95	5757	24	ET	3C	PAB	209.8		96	6201	2	ET	S&D	GSS	385
95	5759	24	ET	3C	UNK	279.5		96	6202	2	ET	S&D	DQ	1132
95	5760	52	ET	3C	DQ	6.5		96	6202	3	ET	S&D	GSS	118.7
95	5760	50	ET	3C	GSS	90.4		96	6211	34	ET	S&D	UNK	31.5
95	5760	53	ET	3C	KH	6.4		96	6219	66	ET	S&D	DQ	929
95	5760	18	ET	3C	UNK	283.2		96	6219	85	ET	S&D	GSS	48.3
95	5762	1	ET	3C	DQ	289.9		96	6219	88	ET	S&D	PAB	405
95	5764	2	ET	3C	DQ	59.6		96	6220	9	ET	S&D	DQ	266.3
95	5764	73	ET	3C	DQ	44.8		96	6220	10	ET	S&D	UNK	329.5
95	5767	1	ET	3C	PAB	41.5		96	6222	62	ET	S&D	UNK	267.5
95	5778	1	ET	3C	PAB	137.7		96	6223	29	ET	3C	DQ	57.3
95	5778	1	ET	3C	PAB	483.7		96	6223	28	ET	3C	UNK	140
95	5789	7	ET	3C	DQ	586.5		96	6224	45	ET	S&D	DQ	161.3
95	5802	1	ET	3C	PAB	50.5		96	6224	44	ET	S&D	UNK	83
95	5802	8	ET	3C	PAB	163.1		96	6226	9	ET	3C	DQ	60.5
95	5802	172	ET	3C	PAB	214.8		96	6226	8	ET	3C	UNK	268.4
95	5802	134	ET	3C	UNK	40		96	6230	13	ET	3C	GSS	303.3
95	5807	56	ET	3C	DQ	35.5		96	6231	83	ET	S&D	DQ	11.4
95	5807	264	ET	3C	DQ	2400		96	6234	10	ET	S&D	DQ	386.7
95	5807	265	ET	3C	KH	11.5		96	6234	11	ET	S&D	UNK	275.3
95	5807	54	ET	3C	PAB	229.6		96	6237	2	ET	3C	DQ	124.5
95	5807	58	ET	3C	PAB	304		96	6237	1	ET	3C	UNK	161.5
95	5807	57	ET	3C	UNK	12.5		96	6239	1	ET	S&D	PAB	351.1
95	5807	263	ET	3C	UNK	56.1		96	6239	2	ET	S&D	UNK	10.1
95	5807	266	ET	3C	UNK	17.5		96	6244	56	ET	S&D	DQ	41.7
95	5810	60	ET	3C	PAB	140.3		96	6244	55	ET	S&D	GSS	93.8
96	5832	22	ET	3C	PAB	238.6		96	6244	2	ET	S&D	PAB	575
96	5837	26	ET	3C	GSS	139.8		96	6251	1	ET	3C	DQ	228.8
96	5837	27	ET	3C	PAB	302.6		96	6251	18	ET	3C	DQ	564.3
96	5837	25	ET	3C	UNK	222.5		96	6251	2	ET	3C	UNK	84.4
96	5840	5	ET	3C	PAB	199.7		96	6251	4	ET	3C	UNK	146
96	5851	2	ET	3C	PAB	1282		96	6251	25	ET	3C	UNK	4.5
95	5855	12	ET	3C	PAB	4500		96	6251	26	ET	3C	UNK	16.7
95	5856	1	ET	3C	UNK	82.9		96	6254	2	ET	3C	KH	130
96	5860	5	ET	3C	PAB	789.8		96	6255	2	ET	3C	PAB	268.5
96	5863	2	ET	3C	GSS	133		96	6255	3	ET	3C	PAB	143.3
95	5868	25	ET	3C	PAB	576.5		96	6255	1	ET	3C	UNK	379
95	5872	1	ET	3C	PAB	1123		96	6256	1	ET	3C	GSS	656
95	5876	1	ET	3C	DQ	2569		96	6257	1	ET	3C	PAB	810.3
95	5900	41	ET	3C	PAB	506.5		96	6300	22	ET	S&D	GSS	181
95	5902	8	ET	3C	GSS	1082		96	6303	73	ET	S&D	GSS	103.2
95	5902	9	ET	3C	PAB	1141		96	6310	153	ET	3C	UNK	44.4

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
96	6351	5	ET	3C	GSS	876.5		95	7013	1	AB	S&D	DQ	1081
96	6351	6	ET	3C	UNK	817.2		95	7015	1	AB	3C	PAB	623.6
95	6503	32	ET	3C	PAB	694		95	7015	2	AB	3C	UNK	350
95	6503	67	ET	3C	PAB	75.6		95	7016	11	AB	3C	UNK	42.9
95	6512	29	ET	2	PAB	257.6		96	7101	13	E	S&D	DQ	14.4
95	6525	13	ET	3C	DQ	42.1		96	7103	11	E	S&D	GSS	9.2
95	6525	24	ET	3C	PAB	217.4		96	7103	12	E	S&D	PAB	91.5
95	6527	1	ET	2	PAB	157.2		96	7103	13	E	S&D	PAB	117.3
95	6532	8	ET	2	PAB	143.2		96	7103	24	E	S&D	PAB	201.7
95	6538	38	ET	2	KH	38.4		96	7103	14	E	S&D	UNK	225.5
95	6547	3	ET	3C	DQ	105		96	7103	15	E	S&D	UNK	50.8
95	6605	2	ET	3C	UNK	61.3		96	7104	139	E	S&D	UNK	59
95	6612	1	ET	3C	GSS	171.7		96	7109	1	E	3C	KH	1161
95	6619	1	ET	3C	PAB	530.5		96	7113	3	E	S&D	DQ	120.2
97	6645	5	ET	3B	PAB	383.5		96	7113	4	E	S&D	GSS	18.5
97	6686	17	ET	3B	PAB	253.3		96	7114	1	E	S&D	DQ	230.6
95	6703	2	E	3C	DQ	80		96	7114	4	E	S&D	UNK	416.3
95	6703	1	E	3C	UNK	106.3		96	7115	15	E	3C	DQ	251.7
95	6716	1	E	3C	UNK	129		96	7115	14	E	3C	PAB	214
95	6716	2	E	3C	UNK	80		96	7115	13	E	3C	UNK	143
96	6821	18	E	S&D	KH	2992		96	7118	53	E	3C	UNK	2.6
96	6821	128	E	S&D	UNK	458		96	7121	84	E	3C	UNK	7.3
96	6821	135	E	S&D	UNK	39.7		96	7123	5	E	3C	PAB	623.6
96	6838	2	E	3C	GSS	207		96	7123	4	E	3C	UNK	144.3
96	6838	38	E	3C	PAB	191.8		96	7144	7	E	3C	PAB	165.3
96	6838	39	E	3C	PAB	198.5		96	7148	43	E	3C	UNK	89.5
96	6862	23	E	3C	UNK	214		96	7149	78	E	S&D	UNK	15.5
96	6864	25	E	3C	PAB	654.8		96	7150	6	E	S&D	DQ	261.7
96	6868	28	E	3C	DQ	121.7		96	7150	22	E	S&D	DQ	22.9
96	6868	35	E	3C	PAB	972.4		96	7155	9	E	3C	UNK	13.2
96	6876	25	E	3C	GSS	23.5		96	7156	19	E	3C	UNK	76.6
96	6882	14	E	3C	PAB	766.1		96	7201	12	F	S&D	UNK	3189
96	6884	9	E	3C	PAB	266		96	7202	5	F	S&D	DQ	151.3
96	6912	10	E	3C	UNK	450		96	7203	8	F	S&D	DQ	198
96	6923	7	E	3C	PAB	254.3		96	7205	2	F	S&D	DQ	1850
96	6963	15	E	3C	DQ	318.1		96	7205	11	F	S&D	DQ	1954
96	6972	3	E	3C	PAB	669		96	7209	40	F	S&D	GSS	189.7
96	6972	4	E	3C	PAB	261.8		96	7210	14	F	S&D	UNK	219.8
97	6989	15	E	S&D	UNK	309.5		96	7212	4	F	S&D	PAB	295.2
97	6989	16	E	S&D	UNK	190.5		96	7218	6	F	S&D	KH	25.2
95	7000	11	AB	S&D	UNK	297.5		96	7227	34	F	3C	DQ	111
95	7002	12	AB	S&D	PAB	749.3		96	7227	35	F	3C	PAB	362.1
95	7003	17	AB	S&D	KH	27.5		96	7229	5	F	3C	UNK	27.8
95	7004	14	AB	S&D	DQ	158.7		96	7230	2	F	S&D	DQ	917.2
95	7004	12	AB	S&D	UNK	18.7		96	7230	34	F	S&D	DQ	152.9

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams	year	lot	record	location	context	material	grams
96	7232	46	F	3C	PAB	73.9	96	7466	13	AB	2	KH	3600
96	7243	26	F	S&D	UNK	2.5	96	7467	297	AB	3A	KH	682.4
96	7243	69	F	S&D	UNK	219	96	7467	298	AB	3A	KH	976
96	7248	2	F	3C	PAB	79.3	96	7467	299	AB	3A	KH	1146
96	7254	53	F	3B	PAB	365.2	96	7467	302	AB	3A	UNK	127.5
96	7256	41	F	3B	PAB	43.4	96	7482	1	AB	2	KH	168.9
96	7257	54	F	3B	KH	211.5	96	7482	5	AB	2	KH	153.4
96	7257	52	F	3B	UNK	187.9	96	7490	39	AB	2	KH	4.5
96	7257	53	F	3B	UNK	209.9	96	7490	40	AB	2	KH	5
96	7257	55	F	3B	UNK	69.5	96	7490	38	AB	2	UNK	25
96	7263	6	F	3C	UNK	1118	96	7491	7	AB	1	KH	99.7
96	7291	1	F	3B	PAB	294.5	96	7491	9	AB	1	UNK	1
96	7310	17	AB	5	DQ	3	96	7492	4	AB	1	KH	32.9
96	7317	1	AB	5	UNK	659.2	96	7492	5	AB	1	KH	20
96	7319	1	AB	4	KH	347.2	96	7493	5	AB	1	KH	81
96	7329	3	AB	5	UNK	121.2	96	7493	4	AB	1	UNK	259
96	7333	28	AB	5	GSS	10.7	96	7495	10	AB	1	KH	72.5
96	7333	31	AB	5	PAB	184.9	96	7496	13	AB	1	KH	119.9
96	7344	1	AB	5	DQ	10.9	96	7496	14	AB	1	KH	68.3
96	7351	9	AB	5	UNK	4	96	7497	17	AB	1	KH	287.5
96	7355	9	AB	5	DQ	53.5	96	7498	4	AB	1	KH	2750
96	7356	57	AB	4	DQ	24.5	96	7498	5	AB	1	KH	153
96	7356	61	AB	4	DQ	70	96	7500	25	AB	1	KH	31.9
96	7356	60	AB	4	GSS	122.5	96	7503	2	AB	1	KH	189.9
96	7356	54	AB	4	PAB	72.2	96	7512	161	AB	1	KH	346.5
96	7356	58	AB	4	UNK	18.8	97	7603	1	F	3C	PAB	430
96	7357	4	AB	5	DQ	666.3	97	7607	26	F	3C	GSS	15.2
96	7357	2	AB	5	UNK	251.6	97	7608	1	F	3C	DQ	2595
96	7359	6	AB	4	KH	164.8	97	7608	2	F	3C	PAB	111.2
96	7373	3	AB	4	UNK	80	97	7617	10	F	3C	PAB	467
96	7375	15	AB	4	DQ	160.3	97	7617	11	F	3C	UNK	57
96	7375	8	AB	4	UNK	47.8	97	7619	19	F	3C	DQ	22.1
96	7401	19	AB	3A	UNK	228.8	99	7631	4	F	3C	DQ	913.5
96	7402	88	AB	3A	PAB	1160	99	7631	5	F	3C	DQ	176.5
96	7403	6	AB	3A	PAB	253	99	7631	6	F	3C	DQ	128.5
96	7419	35	AB	2	KH	29.8	99	7631	9	F	3C	DQ	2500
96	7423	84	AB	2	KH	39	99	7631	11	F	3C	DQ	1262
96	7423	3	AB	2	UNK	114.5	99	7631	13	F	3C	DQ	466
96	7423	93	AB	2	UNK	12.3	99	7631	18	F	3C	DQ	84
96	7431	9	AB	2	UNK	400	99	7631	15	F	3C	GSS	330
96	7451	2	AB	S&D	PAB	44.5	99	7631	3	F	3C	PAB	1258
96	7460	8	AB	2	KH	253.8	99	7631	8	F	3C	PAB	3500
96	7460	7	AB	2	UNK	242.1	99	7631	12	F	3C	PAB	874
96	7460	48	AB	2	UNK	4.5	99	7631	10	F	3C	UNK	1409
96	7462	6	AB	2	KH	1321	99	7631	14	F	3C	UNK	422

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
99	7631	16	F	3C	UNK	174		99	7792	5	AB	3C	UNK	91.5
99	7631	17	F	3C	UNK	151		99	7793	1	AB	3C	PAB	50.2
99	7631	28	F	3C	UNK	53.3		99	7798	4	AB	3C	DQ	20
99	7633	8	F	3C	DQ	892.8		99	7798	3	AB	3C	KH	68.3
99	7633	9	F	3C	PAB	289		97	7814	8	ET	S&D	PAB	1016
99	7635	15	F	3C	UNK	216.4		97	7816	1	ET	S&D	PAB	252.5
99	7635	56	F	3C	UNK	477		97	7817	1	ET	S&D	DQ	498
99	7643	5	F	3C	DQ	255.6		97	7817	1	ET	S&D	UNK	332
99	7643	4	F	3C	PAB	218.4		97	7819	21	ET	3B	DQ	290
99	7647	1	F	3C	GSS	800.9		97	7819	2	ET	3B	PAB	326
99	7648	2	F	3C	UNK	950.4		97	7824	52	ET	3B	UNK	104.6
99	7666	7	F	S&D	DQ	2270		97	7825	8	ET	3B	PAB	9000
99	7666	8	F	S&D	DQ	2690		97	7835	1	ET	3B	PAB	348.8
99	7666	9	F	S&D	DQ	1696		97	7844	1	ET	S&D	PAB	115.7
99	7666	24	F	S&D	DQ	1266		97	7851	20	ET	3B	PAB	1170
99	7666	25	F	S&D	DQ	657		97	8025	4	E	3B	KH	26.6
99	7666	5	F	S&D	GSS	1013		97	8053	21	E	3C	UNK	428.2
99	7666	16	F	S&D	GSS	311.5		97	8081	3	E	3C	PAB	408.7
99	7666	28	F	S&D	GSS	763		97	8105	6	E	S&D	PAB	384
99	7666	17	F	S&D	KH	185.7		97	8107	12	E	3C	PAB	250.9
99	7666	10	F	S&D	PAB	1866		97	8107	13	E	3C	PAB	580.4
99	7666	12	F	S&D	PAB	588		97	8107	22	E	3C	PAB	1040
99	7666	15	F	S&D	PAB	375		97	8107	55	E	3C	PAB	311
99	7666	22	F	S&D	PAB	1341		97	8108	1	E	3C	PAB	1277
99	7666	23	F	S&D	PAB	1158		97	8109	1	E	S&D	DQ	400
99	7666	26	F	S&D	PAB	1161		97	8110	3	E	S&D	PAB	353.6
99	7666	6	F	S&D	UNK	571.1		97	8110	4	E	S&D	PAB	322.4
99	7666	11	F	S&D	UNK	370.5		97	8111	33	E	3C	DQ	362.1
99	7666	13	F	S&D	UNK	1016		97	8111	34	E	3C	UNK	105.7
99	7666	14	F	S&D	UNK	133		97	8113	4	E	3C	DQ	66.6
99	7666	20	F	S&D	UNK	1202		97	8113	3	E	3C	PAB	151
99	7666	21	F	S&D	UNK	809.8		97	8115	14	E	3C	DQ	1057
99	7666	27	F	S&D	UNK	590.8		97	8115	13	E	3C	GSS	405.8
99	7666	35	F	S&D	UNK	518.8		97	8115	15	E	3C	PAB	1478
98	7680	3	F	3C	PAB	300		97	8115	40	E	3C	UNK	142.3
97	7701	182	AB	3C	GSS	182		97	8121	4	E	3C	PAB	1700
97	7715	6	AB	S&D	UNK	308		98	8154	12	E	3C	DQ	81.7
97	7715	10	AB	S&D	UNK	7000		98	8154	11	E	3C	UNK	188.9
97	7740	3	AB	S&D	DQ	231.2		98	8158	44	E	3C	DQ	470
97	7743	1	AB	S&D	PAB	80.9		98	8158	75	E	3C	DQ	600.1
97	7781	24	AB	S&D	PAB	157.3		98	8158	3	E	3C	PAB	346.1
97	7784	804	AB	S&D	UNK	111.9		98	8158	63	E	3C	UNK	127.7
99	7790	2	AB	3C	UNK	95.4		98	8158	79	E	3C	UNK	195.9
99	7790	15	AB	3C	UNK	202.2		98	8159	36	E	3C	DQ	181.5
99	7791	8	AB	3C	UNK	250.3		98	8159	37	E	3C	PAB	243.3

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
98	8161	49	E	3C	DQ	784.1		97	8201	4	E	3B	GSS	761.5
98	8161	23	E	3C	UNK	165.2		97	8245	1	E	3C	PAB	1260
98	8163	11	E	3C	PAB	499.5		98	8301	81	AB	S&D	GSS	277
98	8163	12	E	3C	PAB	67.5		98	8301	64	AB	S&D	KH	199.5
98	8163	8	E	3C	UNK	317.5		98	8301	66	AB	S&D	UNK	300
98	8165	17	E	S&D	PAB	730		98	8301	163	AB	S&D	UNK	200
98	8165	32	E	S&D	PAB	1247		98	8302	36	AB	S&D	PAB	58.2
98	8165	104	E	S&D	PAB	207		98	8302	35	AB	S&D	UNK	185.3
98	8165	105	E	S&D	PAB	558.8		98	8303	37	AB	S&D	UNK	47.7
98	8165	126	E	S&D	PAB	379.7		98	8303	39	AB	S&D	UNK	5.4
98	8165	16	E	S&D	UNK	53.9		98	8304	2	AB	S&D	KH	116.1
98	8165	33	E	S&D	UNK	1204		98	8305	82	AB	S&D	DQ	1.2
98	8165	99	E	S&D	UNK	93.5		98	8305	10	AB	S&D	KH	1.25
98	8165	100	E	S&D	UNK	136.1		98	8305	8	AB	S&D	UNK	82.9
98	8165	101	E	S&D	UNK	73		98	8305	9	AB	S&D	UNK	386.8
98	8165	103	E	S&D	UNK	260.4		98	8305	65	AB	S&D	UNK	120.3
98	8165	124	E	S&D	UNK	260.9		98	8305	81	AB	S&D	UNK	1.9
98	8166	12	E	S&D	PAB	449.4		98	8306	26	AB	S&D	DQ	565.3
98	8166	13	E	S&D	UNK	173		98	8306	262	AB	S&D	DQ	151.6
98	8167	4	E	3C	PAB	116.6		98	8306	84	AB	S&D	GSS	150.9
98	8169	97	E	3C	PAB	468.7		98	8306	198	AB	S&D	GSS	32.4
98	8170	20	E	3C	UNK	27.5		98	8306	221	AB	S&D	KH	363
98	8170	21	E	3C	UNK	114		98	8306	27	AB	S&D	UNK	334.6
98	8172	24	E	S&D	UNK	127.6		98	8306	167	AB	S&D	UNK	249.5
98	8173	40	E	S&D	DQ	544		98	8306	219	AB	S&D	UNK	208.2
98	8173	42	E	S&D	DQ	173.5		98	8306	261	AB	S&D	UNK	75.7
98	8173	90	E	S&D	DQ	159.7		98	8306	262	AB	S&D	UNK	105.9
98	8173	91	E	S&D	DQ	105.7		98	8306	263	AB	S&D	UNK	137.3
98	8173	92	E	S&D	DQ	47.8		98	8308	57	AB	3C	DQ	232.1
98	8173	39	E	S&D	GSS	269.6		98	8308	9	AB	3C	UNK	93.1
98	8173	41	E	S&D	PAB	782.3		98	8308	32	AB	3C	UNK	1610
98	8173	99	E	S&D	UNK	300		98	8309	1	AB	3C	GSS	104.5
98	8173	99	E	S&D	UNK	313		98	8310	110	AB	3C	DQ	1.5
98	8175	13	E	3C	PAB	121.5		98	8310	127	AB	3C	UNK	250.8
98	8175	14	E	3C	PAB	105.9		98	8310	154	AB	3C	UNK	321.3
98	8176	111	E	3C	DQ	260		98	8311	7	AB	3C	KH	38.2
98	8176	25	E	3C	PAB	576		98	8311	8	AB	3C	KH	19.8
98	8176	26	E	3C	UNK	49.8		98	8313	159	AB	S&D	DQ	53.5
98	8176	45	E	3C	UNK	274.9		98	8314	16	AB	3C	KH	19.5
98	8183	15	E	3C	UNK	339.7		98	8315	6	AB	3C	UNK	332.2
98	8183	16	E	3C	UNK	137.1		98	8315	7	AB	3C	UNK	140.8
98	8185	8	E	3C	PAB	281.2		98	8315	8	AB	3C	UNK	57.1
98	8198	22	E	3C	DQ	57.9		98	8321	6	AB	3C	GSS	235.5
98	8198	23	E	3C	DQ	373.3		98	8322	2	AB	3C	DQ	125
98	8198	25	E	3C	DQ	115.8		98	8322	118	AB	3C	DQ	377.2

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
98	8322	126	AB	3C	KH	77.8		98	8404	1091	AB	S&D	DQ	13.2
98	8322	124	AB	3C	UNK	20.2		98	8404	1092	AB	S&D	DQ	12.4
98	8322	125	AB	3C	UNK	7.7		98	8404	1096	AB	S&D	DQ	2.3
98	8323	50	AB	3C	UNK	89.4		98	8404	1139	AB	S&D	DQ	545
98	8326	124	AB	3C	DQ	186		98	8404	113	AB	S&D	KH	180.4
98	8326	125	AB	3C	KH	41.9		98	8404	115	AB	S&D	KH	129.7
98	8328	23	AB	3C	DQ	269.5		98	8404	116	AB	S&D	KH	50
98	8331	73	AB	S&D	DQ	31		98	8404	120	AB	S&D	KH	322
98	8331	37	AB	S&D	UNK	200		98	8404	160	AB	S&D	KH	888.8
98	8332	15	AB	S&D	DQ	201		98	8404	356	AB	S&D	KH	1280
98	8332	3	AB	S&D	KH	557.9		98	8404	1088	AB	S&D	KH	67.7
98	8332	16	AB	S&D	UNK	100		98	8404	1089	AB	S&D	KH	26.8
98	8334	84	AB	S&D	PAB	138		98	8404	1093	AB	S&D	KH	267
98	8334	2	AB	S&D	UNK	3000		98	8404	1094	AB	S&D	KH	25.9
98	8334	6	AB	S&D	UNK	117.7		98	8404	1095	AB	S&D	KH	3.7
98	8334	7	AB	S&D	UNK	150.5		98	8404	1082	AB	S&D	PAB	370
98	8336	87	AB	3C	GSS	304.2		98	8404	1084	AB	S&D	PAB	162.5
98	8340	13	AB	3C	GSS	198.3		98	8404	1085	AB	S&D	PAB	73
98	8341	44	AB	3C	DQ	13.5		98	8404	1087	AB	S&D	PAB	48.4
98	8341	53	AB	3C	DQ	81.4		98	8404	117	AB	S&D	UNK	33.5
98	8341	54	AB	3C	DQ	62.7		98	8404	119	AB	S&D	UNK	1006
98	8347	129	AB	3C	DQ	135.3		98	8404	127	AB	S&D	UNK	393
98	8366	12	AB	3B	PAB	285.3		98	8404	191	AB	S&D	UNK	450
98	8375	74	AB	3B	UNK	48.2		98	8404	1086	AB	S&D	UNK	98.2
98	8377	6	AB	3B	UNK	593.7		98	8404	1140	AB	S&D	UNK	423
98	8380	3	AB	3C	KH	6.9		98	8408	12	AB	2	KH	4.5
99	8385	27	AB	S&D	KH	34.4		98	8409	48	AB	2	KH	182.9
99	8387	110	AB	S&D	UNK	145		98	8412	154	AB	3A	KH	99.9
99	8388	133	AB	S&D	PAB	240.1		98	8412	260	AB	3A	KH	39.7
99	8388	120	AB	S&D	UNK	225.3		98	8412	193	AB	3A	PAB	75
99	8388	121	AB	S&D	UNK	36		98	8412	208	AB	3A	PAB	156.3
99	8393	140	AB	3C	GSS	216.5		98	8412	209	AB	3A	PAB	720.7
99	8394	22	AB	S&D	DQ	207		98	8412	124	AB	3A	UNK	65.1
99	8394	45	AB	S&D	PAB	322		98	8412	125	AB	3A	UNK	131.5
99	8394	24	AB	S&D	UNK	10.9		98	8412	166	AB	3A	UNK	750
99	8394	33	AB	S&D	UNK	76.3		98	8412	194	AB	3A	UNK	157.7
99	8394	44	AB	S&D	UNK	170.3		98	8412	207	AB	3A	UNK	72.3
99	8394	46	AB	S&D	UNK	830		98	8413	31	AB	2	KH	63.4
99	8395	58	AB	S&D	UNK	280.9		98	8416	2	AB	3A	UNK	3.8
99	8395	73	AB	S&D	UNK	173.8		98	8416	11	AB	3A	UNK	286.7
99	8395	74	AB	S&D	UNK	48.2		98	8424	13	AB	2	KH	31.5
99	8398	16	AB	3B	KH	154.5		98	8427	23	AB	2	KH	158.9
98	8404	114	AB	S&D	DQ	234.7		98	8427	24	AB	2	PAB	176.8
98	8404	1083	AB	S&D	DQ	71.5		98	8428	27	AB	2	KH	1224
98	8404	1090	AB	S&D	DQ	59.5		98	8428	28	AB	2	KH	15.4

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
98	8428	33	AB	2	KH	4.2		99	8492	38	AB	2	KH	148.3
98	8429	19	AB	2	KH	82.2		99	8492	39	AB	2	KH	161.9
98	8430	24	AB	2	KH	333.6		99	8492	233	AB	2	KH	11.4
98	8430	25	AB	2	KH	143.7		99	8492	234	AB	2	KH	284.8
98	8430	26	AB	2	KH	94.9		99	8492	235	AB	2	KH	25.8
98	8430	27	AB	2	KH	40.9		99	8492	246	AB	2	KH	158.3
98	8430	28	AB	2	KH	44.3		99	8492	247	AB	2	KH	22.2
98	8430	23	AB	2	UNK	90		99	8492	248	AB	2	KH	72.1
98	8430	59	AB	2	UNK	117.9		99	8492	249	AB	2	KH	82.7
98	8431	5	AB	2	KH	102.7		99	8492	250	AB	2	KH	90.3
98	8432	50	AB	2	KH	138.7		99	8492	251	AB	2	KH	115
98	8433	11	AB	2	PAB	318.5		99	8492	252	AB	2	KH	139.8
98	8433	40	AB	2	UNK	23.4		99	8492	253	AB	2	KH	66.8
98	8436	11	AB	2	KH	64.5		99	8492	15	AB	2	UNK	146.8
98	8436	12	AB	2	KH	65.4		99	8493	13	AB	2	KH	130.1
98	8436	13	AB	2	KH	68.7		98	8499	174	AB	2	UNK	2103
98	8436	14	AB	2	KH	79.8		98	8499	295	AB	2	UNK	1332
98	8436	27	AB	2	KH	2500		98	8501	6	AB	1	UNK	20.3
98	8436	29	AB	2	KH	18.2		98	8502	7	AB	1	PAB	19.2
98	8437	16	AB	2	PAB	51.8		98	8503	8	AB	1	KH	7.7
98	8439	26	AB	S&D	KH	103.1		98	8503	9	AB	1	KH	149.8
98	8439	27	AB	S&D	UNK	46.3		98	8509	9	AB	1	KH	7.1
98	8439	70	AB	S&D	UNK	10.4		98	8509	9	AB	1	KH	18.4
98	8440	80	AB	S&D	KH	34.5		98	8511	31	AB	1	KH	25.7
98	8440	3	AB	S&D	UNK	100.3		98	8515	9	AB	1	GSS	76
98	8440	79	AB	S&D	UNK	218.5		98	8517	3	AB	1	KH	18.1
98	8452	6	AB	2	KH	67.3		98	8517	4	AB	1	KH	31.4
98	8461	7	AB	2	UNK	33.5		98	8518	8	AB	1	KH	172.1
98	8463	1	AB	2	KH	154.7		98	8518	9	AB	1	KH	80.5
98	8480	11	AB	1	KH	34.8		98	8518	10	AB	1	KH	63.6
98	8482	8	AB	1	KH	132.4		98	8518	17	AB	1	KH	65.3
98	8486	30	AB	2	KH	364.4		98	8518	18	AB	1	KH	49.5
98	8486	31	AB	2	KH	187.5		98	8518	19	AB	1	KH	38
98	8486	3	AB	2	UNK	170.5		98	8518	20	AB	1	KH	34.5
98	8486	29	AB	2	UNK	66.8		98	8518	21	AB	1	KH	23.5
98	8487	37	AB	2	KH	27		98	8518	22	AB	1	KH	20.2
98	8487	38	AB	2	KH	216.5		98	8518	23	AB	1	KH	12.5
98	8490	102	AB	2	DQ	22		98	8525	5	AB	1	KH	6.3
99	8490	99	AB	2	KH	17		98	8528	4	AB	1	KH	43.3
99	8490	100	AB	2	KH	65		98	8530	11	AB	1	UNK	137.4
99	8490	101	AB	2	KH	24		98	8531	1	AB	1	KH	120
99	8490	121	AB	2	KH	114		98	8531	2	AB	1	UNK	105.5
99	8492	35	AB	2	KH	290		98	8532	2	AB	1	KH	95
99	8492	36	AB	2	KH	136.3		98	8533	7	AB	1	DQ	80.2
99	8492	37	AB	2	KH	129.1		98	8544	8	AB	1	KH	1491

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams
98	8551	1	AB	1	KH	86.2
98	8554	3	AB	1	GSS	28.3
98	8562	28	AB	1	UNK	269.9
98	8576	1	AB	1	KH	176.2
98	8582	17	AB	1	KH	89.4
98	8588	10	AB	1	KH	3.8
98	8588	11	AB	1	KH	18.8
98	8590	3	AB	1	KH	520.5
98	8600	10	F	S&D	GSS	970
98	8600	9	F	S&D	PAB	520
98	8600	31	F	S&D	PAB	240
98	8601	10	F	S&D	DQ	142
98	8601	9	F	S&D	UNK	71
98	8602	8	F	S&D	DQ	300
98	8602	7	F	S&D	UNK	152.9
98	8603	46	F	S&D	DQ	42.4
98	8603	47	F	S&D	PAB	292.7
98	8603	48	F	S&D	PAB	133.3
98	8603	5	F	S&D	UNK	115
98	8604	21	F	S&D	PAB	1101
98	8607	1	F	S&D	DQ	6000
98	8607	56	F	S&D	DQ	639.9
98	8607	55	F	S&D	UNK	29.3
98	8609	9	F	3C	UNK	991.5
98	8616	24	F	S&D	UNK	346
98	8617	1	F	3C	DQ	55.7
98	8619	5	F	3C	DQ	20.6
98	8625	10	F	3C	DQ	90.5
98	8625	9	F	3C	UNK	282
98	8630	55	F	3C	UNK	50
98	8636	1	F	3C	DQ	57
98	8639	3	F	3C	UNK	321.5
98	8641	8	F	3C	DQ	58.3
98	8641	7	F	3C	GSS	598.4
98	8641	9	F	3C	PAB	807.7
98	8642	2	F	3C	GSS	2266
98	8642	4	F	3C	KH	204
98	8642	5	F	3C	UNK	607
98	8645	3	F	3C	UNK	56.3
98	8649	15	F	3C	DQ	58.8
98	8652	2	F	3C	PAB	27.5
98	8654	24	F	3C	PAB	123
98	8660	3	F	3C	UNK	38.5
98	8662	2	F	3C	UNK	115.3
98	8662	8	F	3C	UNK	72.5
98	8663	22	F	3C	DQ	184.5
98	8667	41	F	3C	DQ	558
98	8667	42	F	3C	DQ	122.5
98	8668	26	F	3C	UNK	41.5
98	8669	13	F	S&D	PAB	102.3
98	8673	15	F	S&D	UNK	167.3
98	8679	7	F	3C	PAB	529.3
98	8684	7	F	3C	UNK	116.4
98	8707	2	F	3C	UNK	3.3
98	8717	4	F	3C	PAB	7.8
98	8727	3	F	3C	DQ	180.6
98	8727	5	F	3C	GSS	244.2
98	8727	4	F	3C	UNK	184.8
98	8727	7	F	3C	UNK	1570
2000	8750	8	F	S&D	UNK	125
2000	8753	16	F	S&D	DQ	185.7
99	8754	34	F	3C	DQ	208.1
99	8754	35	F	3C	DQ	98.7
99	8754	33	F	3C	KH	258.9
99	8754	2	F	3C	PAB	800.5
99	8754	36	F	3C	UNK	264.5
99	8754	37	F	3C	UNK	7.4
99	8755	74	F	3C	DQ	50.6
99	8755	82	F	3C	DQ	257.5
99	8755	77	F	3C	GSS	813.5
99	8755	81	F	3C	GSS	346.5
99	8755	79	F	3C	KH	304.5
99	8755	75	F	3C	PAB	44.2
99	8755	78	F	3C	PAB	350.8
99	8755	83	F	3C	UNK	31.1
99	8756	69	F	3C	GSS	545.5
99	8756	87	F	3C	GSS	131.8
99	8756	43	F	3C	PAB	133.9
99	8756	45	F	3C	PAB	249.4
99	8756	46	F	3C	PAB	711
99	8756	80	F	3C	PAB	641.3
99	8756	84	F	3C	PAB	227.8
99	8756	40	F	3C	UNK	178
99	8756	42	F	3C	UNK	95.9
99	8756	44	F	3C	UNK	193.1
99	8757	78	F	3C	DQ	446.5
99	8757	79	F	3C	DQ	83.7
99	8757	80	F	3C	DQ	280.5
99	8757	81	F	3C	UNK	169.3
99	8757	82	F	3C	UNK	51.9

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
99	8757	214	F	3C	UNK	92.9		99	8777	40	F	3C	UNK	43.7
99	8758	4	F	3C	UNK	40		99	8777	41	F	3C	UNK	12.1
99	8758	5	F	3C	UNK	87.8		99	8777	42	F	3C	UNK	13.8
99	8758	6	F	3C	UNK	87.6		99	8778	50	F	3C	UNK	84.3
99	8758	7	F	3C	UNK	39.8		99	8778	51	F	3C	UNK	28.9
99	8760	155	F	3C	KH	34.3		99	8779	24	F	3C	DQ	165
99	8760	39	F	3C	UNK	24.7		99	8780	46	F	3C	DQ	631.7
99	8760	42	F	3C	UNK	83.7		99	8780	66	F	3C	DQ	6.3
99	8760	43	F	3C	UNK	31.9		99	8780	47	F	3C	UNK	56.7
99	8760	44	F	3C	UNK	68.4		99	8780	73	F	3C	UNK	20.5
99	8763	77	F	3C	PAB	157		99	8788	28	F	3C	PAB	470.8
99	8763	40	F	3C	UNK	43.7		99	8795	20	F	3C	DQ	231.7
99	8763	41	F	3C	UNK	57.5		99	8795	21	F	3C	UNK	121.9
99	8763	74	F	3C	UNK	7.2		99	8796	23	F	3C	DQ	3.5
99	8763	78	F	3C	UNK	335		99	8796	31	F	3C	DQ	254.7
99	8764	122	F	S&D	DQ	598		99	8796	30	F	3C	UNK	712
99	8764	144	F	S&D	DQ	13.7		99	8806	28	E	S&D	UNK	18.6
99	8764	173	F	S&D	DQ	7.2		99	8821	32	E	3C	DQ	384.4
99	8764	136	F	S&D	PAB	1.7		99	8821	33	E	3C	DQ	570.9
99	8764	140	F	S&D	UNK	137.6		99	8821	23	E	3C	GSS	980.6
99	8764	142	F	S&D	UNK	3.7		99	8827	18	E	3C	KH	978.8
99	8764	145	F	S&D	UNK	36.8		99	8828	7	E	S&D	PAB	70.5
99	8764	171	F	S&D	UNK	4.6		99	8829	31	E	S&D	DQ	39.4
99	8764	174	F	S&D	UNK	44.5		99	8830	2	E	S&D	PAB	390.1
99	8764	245	F	S&D	UNK	57.8		99	8830	3	E	S&D	PAB	80.9
99	8764	266	F	S&D	UNK	8.8		99	8831	4	E	S&D	DQ	49.6
99	8774	70	F	3C	DQ	177.1		99	8831	5	E	S&D	PAB	1059
99	8774	12	F	3C	GSS	199		99	8832	1	E	3C	DQ	584.3
99	8774	86	F	3C	KH	16		99	8834	9	E	3C	DQ	1490
99	8774	67	F	3C	UNK	2.1		99	8840	1	E	S&D	PAB	375.7
99	8774	87	F	3C	UNK	78		99	8843	7	E	S&D	PAB	149.6
99	8775	32	F	3C	GSS	33.9		99	8844	9	E	S&D	DQ	43.2
99	8775	33	F	3C	UNK	21		99	8845	12	E	S&D	UNK	31.8
99	8776	62	F	3C	DQ	382.5		99	8846	3	E	S&D	UNK	107.1
99	8776	121	F	3C	KH	128.2		99	8857	6	E	3C	DQ	9.1
99	8776	63	F	3C	PAB	963.9		99	8858	34	E	3C	UNK	21.5
99	8776	120	F	3C	PAB	844		99	8858	38	E	3C	UNK	294
99	8776	46	F	3C	UNK	246.3		99	8859	51	E	3C	DQ	267
99	8776	117	F	3C	UNK	5500		99	8859	46	E	3C	KH	32.1
99	8777	39	F	3C	GSS	17.9		99	8859	8	E	3C	PAB	343.3
99	8777	26	F	3C	UNK	8.7		99	8859	47	E	3C	PAB	370
99	8777	27	F	3C	UNK	150.6		99	8859	49	E	3C	PAB	133.3
99	8777	28	F	3C	UNK	149.8		99	8859	45	E	3C	SR	116
99	8777	37	F	3C	UNK	44.5		99	8859	48	E	3C	UNK	29.4
99	8777	38	F	3C	UNK	5.4		99	8860	14	E	3C	GSS	227.2

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
99	8860	13	E	3C	PAB	174.3		99	8940	5	AB	S&D	UNK	765.3
99	8864	72	E	S&D	DQ	979		99	8940	9	AB	S&D	UNK	778
99	8864	69	E	S&D	UNK	99.3		99	8940	10	AB	S&D	UNK	863.8
99	8864	70	E	S&D	UNK	51.5		99	8940	11	AB	S&D	UNK	286.9
99	8864	71	E	S&D	UNK	82.3		99	8940	33	AB	S&D	UNK	10.5
99	8866	9	E	3C	PAB	237.5		99	8941	61	AB	2	PAB	225.5
99	8867	39	E	3C	DQ	130.7		99	8941	63	AB	2	UNK	297.7
99	8871	4	E	3C	DQ	137.1		99	8943	61	AB	2	KH	72.3
99	8884	2	E	S&D	DQ	490.4		99	8944	81	AB	2	KH	90.5
99	8884	3	E	S&D	UNK	378		99	8944	82	AB	2	KH	26
99	8887	13	E	S&D	DQ	22.2		99	8944	85	AB	2	KH	45.3
99	8889	16	E	3C	PAB	733		99	8950	24	AB	2	PAB	192.1
99	8890	31	E	3C	DQ	35.7		99	8954	11	AB	2	UNK	78.5
99	8890	82	E	3C	KH	378		99	8960	11	AB	2	KH	70.7
99	8890	74	E	3C	PAB	923		99	8960	12	AB	2	KH	105.8
99	8890	80	E	3C	PAB	391		99	8961	18	AB	2	KH	177.8
99	8890	99	E	3C	PAB	454		99	8963	1	AB	2	KH	155
99	8890	32	E	3C	UNK	66.8		99	8963	13	AB	2	KH	326.5
99	8890	33	E	3C	UNK	81.1		99	8963	14	AB	2	KH	260
99	8894	20	E	S&D	DQ	583		2000	8983	53	AB	2	KH	100.2
99	8896	20	E	3C	UNK	26.6		2000	8983	54	AB	2	KH	55.9
99	8898	1	E	3C	UNK	110.1		2000	8984	81	AB	2	KH	726
99	8907	1	AB	1	UNK	205		2000	8990	117	AB	2	GSS	141.2
99	8936	15	AB	2	KH	53.5		2000	8990	84	AB	2	UNK	16.1
99	8938	54	AB	S&D	KH	42.1		2000	8990	118	AB	2	UNK	118
99	8938	55	AB	S&D	KH	170.1		2000	8990	120	AB	2	UNK	44.4
99	8939	229	AB	S&D	DQ	665.8		2000	8996	27	AB	2	KH	1171
99	8939	230	AB	S&D	DQ	178.7		2001	9004	12	E	S&D	DQ	64.5
99	8939	232	AB	S&D	DQ	130.2		2001	9004	18	E	S&D	DQ	231
99	8939	236	AB	S&D	DQ	66.4		2001	9004	16	E	S&D	PAB	558
99	8939	237	AB	S&D	DQ	28.1		2001	9004	8	E	S&D	UNK	130.8
99	8939	243	AB	S&D	DQ	592.5		2001	9006	1	E	S&D	DQ	290.6
99	8939	231	AB	S&D	PAB	109.9		2001	9007	20	E	S&D	UNK	146.1
99	8939	244	AB	S&D	PAB	309.5		2001	9010	21	E	3C	UNK	512.3
99	8939	245	AB	S&D	PAB	323.5		2001	9017	3	E	3C	PAB	95.5
99	8939	246	AB	S&D	PAB	351		2001	9043	3	E	3C	DQ	43
99	8939	238	AB	S&D	UNK	43.7		2001	9044	13	E	3C	PAB	513
99	8939	241	AB	S&D	UNK	87.1		2001	9051	6	E	3C	PAB	663.5
99	8939	242	AB	S&D	UNK	65.8		2001	9051	14	E	3C	PAB	43.8
99	8939	247	AB	S&D	UNK	155		2001	9051	23	E	3C	PAB	54.3
99	8939	248	AB	S&D	UNK	43.5		2001	9056	20	E	3C	UNK	104.7
99	8939	249	AB	S&D	UNK	9.2		2001	9057	14	E	3C	PAB	234
99	8939	250	AB	S&D	UNK	3.2		2001	9059	6	E	3C	PAB	51.3
99	8939	258	AB	S&D	UNK	31		2001	9059	75	E	3C	PAB	277
99	8940	12	AB	S&D	KH	220		2001	9059	76	E	3C	PAB	234

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
2001	9059	5	E	3C	UNK	351		99	9401	38	AB	S&D	UNK	38.5
2001	9059	7	E	3C	UNK	533		99	9401	39	AB	S&D	UNK	3.4
2001	9065	7	E	3C	UNK	25		99	9406	1	AB	3B	DQ	991.6
2001	9067	39	E	S&D	PAB	107		99	9406	2	AB	3B	DQ	660.7
2001	9069	2	E	3C	PAB	113.8		99	9408	38	AB	3B	UNK	375.4
2001	9076	4	E	3C	DQ	304		99	9409	8	AB	3B	KH	398.5
2001	9076	2	E	3C	UNK	251.9		99	9413	124	AB	S&D	KH	151.7
2001	9079	24	E	3C	GSS	303		99	9413	74	AB	S&D	UNK	44.5
2001	9079	21	E	3C	PAB	1071		99	9413	75	AB	S&D	UNK	46
2001	9079	20	E	3C	UNK	1148		99	9413	76	AB	S&D	UNK	22.7
2001	9091	7	E	3C	PAB	342		99	9413	77	AB	S&D	UNK	24.9
2001	9091	8	E	3C	PAB	1462		99	9413	78	AB	S&D	UNK	232.9
2001	9091	10	E	3C	UNK	1202		99	9413	121	AB	S&D	UNK	35.5
2001	9091	54	E	3C	UNK	140		99	9413	122	AB	S&D	UNK	18
2001	9092	2	E	3C	GSS	3000		99	9413	123	AB	S&D	UNK	44.3
2001	9097	1	E	3C	PAB	1394		99	9421	1	AB	3B	KH	29.3
99	9103	2	F	3C	UNK	15.7		99	9432	23	AB	S&D	UNK	30.8
99	9108	39	F	3C	PAB	340.7		99	9432	35	AB	S&D	UNK	645.2
99	9110	39	F	3C	DQ	88.8		99	9435	7	AB	3B	UNK	35.5
99	9110	40	F	3C	DQ	41		2000	9438	26	AB	S&D	KH	35
99	9110	41	F	3C	DQ	27.9		2000	9438	27	AB	S&D	KH	130.9
99	9110	21	F	3C	UNK	24.7		2000	9438	28	AB	S&D	KH	38.4
99	9112	15	F	3C	DQ	271.8		2000	9438	29	AB	S&D	KH	126.5
99	9113	43	F	3C	DQ	248.2		2000	9438	31	AB	S&D	KH	27.7
99	9113	44	F	3C	DQ	234.1		2000	9438	8	AB	S&D	UNK	28.2
99	9115	30	F	3C	DQ	3.6		2000	9438	32	AB	S&D	UNK	44
99	9120	20	F	3C	DQ	218.8		2000	9440	2	AB	S&D	UNK	91.1
99	9120	19	F	3C	GSS	165.1		2000	9444	3	AB	3B	KH	46.6
99	9120	18	F	3C	UNK	4.5		2000	9504	40	AB	2	KH	94
99	9129	2	F	3C	DQ	11		2000	9507	39	AB	2	UNK	111.1
99	9131	1	F	3C	UNK	123		2000	9511	21	AB	2	KH	19.4
99	9203	1	F	S&D	DQ	188.1		2000	9511	1	AB	2	PAB	72
99	9203	2	F	S&D	DQ	133		2000	9514	14	AB	2	KH	84.5
99	9203	3	F	S&D	DQ	126		2000	9514	96	AB	2	UNK	167.6
99	9205	16	F	3C	DQ	261		2000	9522	72	AB	3A	KH	179.7
99	9205	17	F	3C	UNK	158.7		2000	9522	71	AB	3A	PAB	563
99	9210	20	F	S&D	PAB	8.8		2000	9555	11	AB	2	DQ	12
99	9211	17/18	F	S&D	PAB	63.5		2000	9559	3	AB	2	DQ	49.4
99	9237	1	F	3C	PAB	724.8		2000	9586	14	AB	2	KH	34.8
99	9241	1	F	3C	UNK	291.6		2000	9588	37	AB	2	GSS	112.2
99	9400	12	AB	S&D	UNK	8.3		2000	9588	36	AB	2	KH	105.4
99	9400	14	AB	S&D	UNK	622.3		99	9600	8	E	S&D	KH	779.6
99	9401	33	AB	S&D	UNK	12.5		99	9600	1	E	S&D	UNK	3565
99	9401	34	AB	S&D	UNK	10		99	9600	9	E	S&D	UNK	1486
99	9401	37	AB	S&D	UNK	29		99	9604	44	E	S&D	KH	338

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
99	9604	45	E	S&D	PAB	201.8		99	9722	11	F	3C	GSS	418.5
99	9604	46	E	S&D	PAB	425.5		99	9722	12	F	3C	GSS	183.5
99	9606	46	E	S&D	DQ	142.7		99	9722	31	F	3C	GSS	238
99	9606	47	E	S&D	DQ	744		99	9722	10	F	3C	KH	396
99	9606	49	E	S&D	DQ	177.2		99	9722	13	F	3C	UNK	170.3
99	9606	48	E	S&D	PAB	177.7		99	9724	49	F	3C	UNK	120.4
99	9606	50	E	S&D	PAB	106.1		99	9729	88	F	3C	UNK	42.5
2001	9611	67	E	3C	DQ	94		99	9729	92	F	3C	UNK	67
2001	9611	66	E	3C	GSS	28.6		99	9729	93	F	3C	UNK	50
2001	9611	68	E	3C	UNK	17.6		99	9742	5	F	3C	UNK	9.4
2001	9612	103	E	3C	DQ	127.3		99	9742	14	F	3C	UNK	14.3
2001	9612	108	E	3C	DQ	303		99	9743	11	F	S&D	DQ	802
2001	9612	104	E	3C	GSS	117.4		99	9743	21	F	S&D	GSS	140
2001	9612	106	E	3C	GSS	198.5		99	9743	12	F	S&D	PAB	216
2001	9612	107	E	3C	PAB	623.7		99	9749	11	F	3C	DQ	180
2001	9613	5	E	3C	PAB	249.3		99	9752	4	F	3C	PAB	423.7
2001	9613	6	E	3C	PAB	80.9		99	9756	24	F	3C	DQ	912.1
2001	9613	13	E	3C	PAB	21.6		99	9756	25	F	3C	DQ	397
2001	9613	32	E	3C	PAB	67.5		99	9756	26	F	3C	DQ	210.8
2001	9613	2	E	3C	UNK	530.5		99	9756	20	F	3C	GSS	41.3
2001	9614	6	E	3C	DQ	245.8		99	9756	27	F	3C	PAB	35
2001	9614	5	E	3C	PAB	1238		99	9763	34	F	3C	UNK	22
2001	9615	80	E	3C	DQ	113.1		99	9773	13	F	3C	UNK	111.3
2001	9615	1	E	3C	UNK	329.9		99	9778	7	F	3C	UNK	150
99	9700	21	F	S&D	UNK	56.3		99	9779	19	F	3C	DQ	22.4
99	9700	22	F	S&D	UNK	34.5		99	9788	1	F	3C	UNK	3.6
99	9700	23	F	S&D	UNK	62.5		99	9788	5	F	3C	UNK	291.8
99	9700	24	F	S&D	UNK	93.8		2000	9807	12	F	3C	DQ	35.2
99	9702	54	F	3C	DQ	52.8		2000	9810	78	F	3C	DQ	281.7
99	9702	70	F	3C	DQ	192.7		2000	9810	41	F	3C	PAB	353
99	9702	68	F	3C	PAB	2.9		2000	9812	1	F	3C	DQ	27
99	9702	69	F	3C	UNK	3.7		2000	9812	2	F	3C	DQ	26.1
99	9704	12	F	S&D	KH	229.7		2000	9812	4	F	3C	UNK	76.4
99	9704	10	F	S&D	UNK	863.5		2000	9818	12	F	3C	GSS	354
99	9704	11	F	S&D	UNK	300		2000	9818	14	F	3C	PAB	18
99	9704	36	F	S&D	UNK	23.4		2000	9818	15	F	3C	UNK	155.9
99	9714	9	F	3C	PAB	285		2000	9822	8	F	3C	DQ	16
99	9714	1	F	3C	UNK	99.1		2000	9822	9	F	3C	UNK	85.1
99	9714	3	F	3C	UNK	202.4		2000	9829	18	F	3C	PAB	300.3
99	9714	4	F	3C	UNK	128.3		2000	9839	16	F	3C	DQ	36.5
99	9715	3	F	3C	UNK	169.6		2000	9840	12	F	3C	UNK	45.8
99	9716	59	F	S&D	KH	44.5		2000	9841	7	F	3C	DQ	201.8
99	9716	17	F	S&D	UNK	230.4		2000	9841	1	F	3C	GSS	1800
99	9718	24	F	3C	DQ	292.1		2000	9841	4	F	3C	UNK	298
99	9718	3	F	3C	UNK	135.1		2000	9841	6	F	3C	UNK	30.2

Appendix 5.1 (continued)														
year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
2000	9843	3	F	3C	PAB	447		2003	9904	11	AB	3C	UNK	264.9
2000	9844	1	F	3C	UNK	347		2003	9904	22	AB	3C	UNK	456
2000	9845	17	F	3C	DQ	148.2		2003	9904	28	AB	3C	UNK	1565
2000	9846	21	F	3C	UNK	62.6		2003	9904	32	AB	3C	UNK	2500
2000	9862	18	F	3C	UNK	87.1		2003	9904	33	AB	3C	UNK	364
2000	9863	5	F	3C	UNK	222.8		2003	9904	35	AB	3C	UNK	523
2000	9865	2	F	3C	UNK	193.7		2003	9904	37	AB	3C	UNK	385
2000	9879	2	F	3C	UNK	76		2003	9904	40	AB	3C	UNK	375
2000	9880	76	F	3C	DQ	227.9		2003	9904	41	AB	3C	UNK	791.9
2000	9880	77	F	3C	DQ	295		2003	9904	43	AB	3C	UNK	147.9
2000	9880	48	F	3C	UNK	4.9		2004	9905	5	AB	3C	KH	4000
2000	9880	58	F	3C	UNK	35.5		2000	9919	1	AB	2	UNK	220.7
2000	9880	72	F	3C	UNK	122.9		2000	9919	2	AB	2	UNK	366
2000	9881	13	F	3C	UNK	122.9		2000	9924	1	AB	2	DQ	270.8
2000	9890	5	F	3C	DQ	18.4		2000	9932	2	AB	2	UNK	88.3
2003	9904	1	AB	3C	DQ	203		2000	9964	26	AB	2	KH	92.8
2003	9904	23	AB	3C	DQ	292.2		2000	9964	3	AB	2	PAB	168.2
2003	9904	24	AB	3C	DQ	579		2000	9973	1	AB	2	KH	31.1
2003	9904	26	AB	3C	DQ	871		2000	9999	56	n/a	n/a	PAB	3500
2003	9904	27	AB	3C	DQ	1619		2000	9999	160	n/a	n/a	UNK	567
2003	9904	29	AB	3C	DQ	449		2000	9999	165	n/a	n/a	PAB	290.8
2003	9904	44	AB	3C	DQ	235.7		2001	9999	166	n/a	n/a	UNK	86.5
2003	9904	6	AB	3C	GSS	965.6		2000	10000	1	F	3C	PAB	31.2
2003	9904	34	AB	3C	GSS	67.5		2000	10011	1	F	3C	PAB	392
2003	9904	36	AB	3C	GSS	536.8		2000	10025	5	F	3C	UNK	69.9
2003	9904	3	AB	3C	PAB	539.1		2000	10030	1	F	3C	UNK	31
2003	9904	4	AB	3C	PAB	538		2000	10031	6	F	3C	PAB	377
2003	9904	5	AB	3C	PAB	796.7		2000	10036	3	F	3C	DQ	182
2003	9904	7	AB	3C	PAB	350		2000	10044	21	F	3C	DQ	124.1
2003	9904	14	AB	3C	PAB	2500		2000	10047	5	F	3C	DQ	230.8
2003	9904	17	AB	3C	PAB	236		2000	10047	4	F	3C	UNK	166
2003	9904	18	AB	3C	PAB	507		2000	10048	2	F	3C	DQ	2500
2003	9904	19	AB	3C	PAB	204		2000	10050	20	F	3C	DQ	172
2003	9904	20	AB	3C	PAB	678		2000	10063	5	F	3C	DQ	870
2003	9904	21	AB	3C	PAB	417.2		2000	10067	1	F	3C	DQ	1322
2003	9904	25	AB	3C	PAB	1090		2000	10067	2	F	3C	DQ	1332
2003	9904	30	AB	3C	PAB	572		2000	11000	7	AB	2	KH	28.4
2003	9904	31	AB	3C	PAB	1054		2000	11005	1	AB	2	UNK	55.7
2003	9904	38	AB	3C	PAB	466.4		2000	11060	16	AB	1	KH	1
2003	9904	39	AB	3C	PAB	279		2000	11060	17	AB	1	KH	1
2003	9904	42	AB	3C	PAB	1158		2000	11060	15	AB	1	UNK	5.6
2003	9904	2	AB	3C	UNK	278.7		2000	11079	12	AB	2	KH	23.6
2003	9904	8	AB	3C	UNK	690		2000	11084	1	AB	1	PAB	236.8
2003	9904	9	AB	3C	UNK	348		2001	11500	1	E	S&D	UNK	17.3
2003	9904	10	AB	3C	UNK	1082		2001	11504	2	E	S&D	DQ	856

Appendix 5.1 (continued)

year	lot	record	location	context	material	grams		year	lot	record	location	context	material	grams
2001	11505	7	E	S&D	UNK	52.4		2001	11701	26	E	S&D	PAB	2500
2001	11505	20	E	S&D	UNK	70.1		2001	11751	82	E	S&D	DQ	46
2001	11505	21	E	S&D	UNK	72.9		2001	11751	37	E	S&D	PAB	373.9
2001	11521	1	E	3C	DQ	436		2001	11751	38	E	S&D	PAB	201.6
2001	11522	1	E	3C	PAB	126.5		2001	11751	80	E	S&D	PAB	507
2001	11527	2	E	3C	UNK	213.3		2001	11756	45	E	3C	UNK	112
2001	11529	1	E	3C	DQ	439.5		2001	11760	4	E	3C	PAB	285
2001	11531	1	E	3C	PAB	1037		2001	11761	18	E	3C	DQ	11.2
2001	11534	12	E	3C	DQ	256.7		2001	11761	14	E	3C	PAB	408.6
2001	11535	1	E	3C	UNK	544.8		2001	11800	21	E	S&D	UNK	505
2001	11542	18	E	S&D	UNK	193		2001	11801	26	E	S&D	DQ	8
2001	11549	17	E	3C	UNK	52.3		2001	11901	1	E	3C	PAB	583
2001	11559	48	E	3C	DQ	491		2001	11909	2	E	3C	PAB	257.7
2001	11560	17	E	3C	PAB	95		2001	11919	6	E	3C	UNK	29.9
2001	11568	1	E	3C	UNK	141.3		2001	11920	11	E	3C	PAB	778.7
2001	11577	1	E	S&D	PAB	52.1		2001	11920	12	E	3C	UNK	1780
2001	11581	10	E	3C	PAB	240.2								

<u>Appendix 5.2</u>: Grindingstones in the Harappa Museum from pre-1986 excavations

Most of the querns and mullers in the Harappa Museum Reserve Collection from pre-1986 exactions were marked with a Harappa Museum number (HM#). Many were also stenciled with an old excavation number. Those without any numbers were given a temporary one (T#).

Museum / temp #	stenciled #	material	grams		Museum / temp #	stenciled #	material	grams
HM#1524		UNK	1500		HM#10486		GSS	7250
HM#65	980	PAB	5000		HM#10487	3773	PAB	6500
HM#67		GSS	20000		HM#10488	300	DQ	7000
HM#68	3498	PAB	1250		HM#10489	360	PAB	13250
HM#HPA93	HPA222.92	UNK	1750		HM#10491		PAB	10000
HM#10410		UNK	21000		HM#10492	3753	DQ	14000
HM#10420		PAB	4000		HM#10493		GSS	8000
HM#10438		UNK	20500		HM#10494		PAB	10000
HM#10447		UNK	2500		HM#10496		GSS	11500
HM#10452		UNK	3500		HM#10497		UNK	9500
HM#10453		UNK	14000		HM#10498		DQ	9000
HM#10455	980	PAB	5500		HM#10500/1	8641	PAB	6500
HM#10456		DQ	4500		HM#10502		UNK	4500
HM#10457		PAB	1250		HM#10504		PAB	3500
HM#10458		GSS	11000		HM#10505		GSS	1000
HM#10459		GSS	11250		HM#10506		DQ	1000
HM#10460	319	PAB	4500		HM#10507		PAB	1500
HM#10461	37	DQ	15500		HM#10508		UNK	2000
HM#10462	8841	GSS	7250		HM#10509	14031	PAB	3000
HM#10463		GSS	3000		HM#10510		PAB	2500
HM#10464		PAB	11500		HM#10511		GSS	2750
HM#10465	8327	UNK	14500		HM#10512	1719	PAB	3500
HM#10466	334	UNK	9000		HM#10513		UNK	2500
HM#10467		DQ	11000		HM#10515		PAB	2000
HM#10471		PAB	6500		HM#10516		DQ	1250
HM#10472		UNK	14000		HM#10517	36	DQ	3000
HM#10473		GSS	6500		HM#10518	9291	GSS	2500
HM#10474		GSS	7500		HM#10519		GSS	2000
HM#10475	319	PAB	10000		HM#10520		GSS	2250
HM#10477		UNK	14000		HM#10521	319	PAB	5000
HM#10479		UNK	10250		HM#10522		GSS	2500
HM#10480	630	UNK	5500		HM#10523		UNK	1500
HM#10481	347	UNK	3500		HM#10524		UNK	1250
HM#10482		DQ	3500		HM#10525		UNK	1500
HM#10483	3034	UNK	6000		HM#10527		GSS	3500
HM#10484	982	PAB	1750		HM#10528		UNK	2250
HM#10485		PAB	2250		HM#10529	12842	UNK	1250
HM#10530	2775	DQ	1250		HM#10532	12648	GSS	500

Appendix 5.2 (continued)								
Museum / temp #	stenciled #	material	grams		Museum / temp #	stenciled #	material	grams
HM#10533	2400	UNK	1000		T#44		GSS	12500
HM#10536	54.3953	GSS	4000		T#46		UNK	10000
HM#10537		UNK	1000		T#48		GSS	1500
HM#10538		GSS	2000		T#49		UNK	2500
HM#10546	318	PAB	10500		T#50		UNK	4000
HM#10547		PAB	1500		T#57	80798	GSS	9000
HM#10549		GSS	2500		T#58		GSS	6750
HM#10550		UNK	1250		T#59		UNK	7000
T#2	557R	UNK	750		T#60		UNK	22500
T#3		UNK	535		T#61	HPA92-93	PAB	7250
T#4		GSS	563		T#62	HPA_ET/24	PAB	18000
T#5		GSS	442		T#63	982	PAB	4000
T#6		UNK	506		T#64	1719	UNK	4750
T#7		UNK	409		T#66		GSS	8000
T#8		PAB	266		T#69	318	PAB	11500
T#9		PAB	313		T#70	980	PAB	3750
T#10		GSS	506		T#71	3989	PAB	9750
T#11		GSS	335		T#72		UNK	10500
T#12		GSS	424		T#73		UNK	5000
T#13		UNK	737		T#74		PAB	1000
T#14		UNK	712		T#75		DQ	1500
T#15		UNK	852		T#76		DQ	1170
T#16		UNK	500		T#77		UNK	5250
T#18		PAB	1110		T#78		DQ	4000
T#19		UNK	1520		T#79		DQ	843
T#20		UNK	1250		T#80		GSS	769
T#27	PII43/9705	UNK	1500		T#81		UNK	1300
T#28		GSS	1250		T#82		DQ	1000
T#29		UNK	927		T#83		GSS	1250
T#30		UNK	1750		T#84		DQ	1000
T#31		UNK	1000		T#85		UNK	2250
T#32		GSS	1500		T#86		PAB	2000
T#33		UNK	6000		T#87		DQ	1750
T#34		UNK	4000		T#88	982	PAB	9000
T#35		GSS	2750		T#89		DQ	3500
T#36		GSS	2500		T#90		DQ	3500
T#37		GSS	4250		T#91		UNK	5000
T#38		GSS	4500		T#92		PAB	4500
T#39		UNK	4500		T#93		PAB	13250
T#40		UNK	9000		T#94	319	PAB	7500
T#41		UNK	9000		T#95	3634	DQ	1000
T#42		UNK	11500		T#129		UNK	5000
T#43		GSS	3500		T#131		UNK	7000

Appendix 6.1: Elemental concentrations for 9 black chert artifacts from Harappa (parts per million)

Figure 6.1 #	Sample	Period	Trench	Al	Ce	Co	Cr	Eu	Fe	La	Mn	Na	Sc	Sm	V
23	98-8546-5	1	39	3760	1.541	1.644	12.25	0.126	1542	0.984	31.52	1161	1.061	0.284	5.37
24	98-8489-25	2	39	2438	1.475	0.413	18.21	0.136	773	1.471	15.80	579	0.268	0.241	19.84
20	98-8554-18	1	39	3832	1.523	2.133	14.75	0.231	2615	0.977	29.43	1168	1.175	0.298	8.09
22	98-8558-4	1	39	4263	2.279	1.614	9.44	0.139	1981	1.440	25.34	1379	1.113	0.338	6.67
18	96-7517-1	1	39	3258	1.406	1.791	10.46	0.145	1928	0.851	25.79	920	0.928	0.268	5.57
19	96-7490-42	2	39	2345	0.732	0.501	15.67	0.125	1105	0.528	9.50	489	0.165	0.114	14.98
16	89-1062-9	2	52	2872	1.178	1.782	12.83	0.199	1634	0.732	34.09	786	0.965	0.223	6.20
17	2000-9598-4	2	39	2531	0.778	0.450	9.96	0.134	781	0.689	7.16	693	0.129	0.131	8.94
21	2001-2925-17	S&D	54	1826	2.904	0.425	4.73	0.144	575	1.100	5.24	199	0.174	0.369	7.21

Appendix 6.2: Elemental concentrations for black chert samples from the Bolan Pass and Jammu (parts per million)

Location	Sample	Al	Ce	Co	Cr	Eu	Fe	La	Mn	Na	Sc	Sm	V
Dozan, Balochistan	BOLAN-1	2306	1.340	0.569	8.86	0.122	1166	1.664	35.98	259	0.297	0.310	6.66
Dozan, Balochistan	BOLAN-2	2450	1.517	0.388	9.69	0.133	733	2.341	11.12	333	0.458	0.379	8.99
Dozan, Balochistan	BOLAN-3	3022	1.782	2.941	4.87	0.141	2292	1.385	38.64	550	0.536	0.391	2.12
Dozan, Balochistan	BOLAN-4	1887	1.140	0.457	8.53	0.122	1310	1.935	20.38	172	0.302	0.236	9.18
Dozan, Balochistan	BOLAN-5	4059	3.435	1.956	9.23	0.202	2855	4.227	253.1	752	0.879	0.694	7.02
Dozan, Balochistan	BOLAN-6	4216	3.519	0.974	9.88	0.264	1767	6.338	28.10	847	1.136	0.997	9.23
Dozan, Balochistan	BOLAN-7	2374	0.917	0.472	8.28	0.126	706	1.402	9.17	278	0.274	0.204	5.08
Dozan, Balochistan	BOLAN-8	2532	1.005	0.581	8.83	0.122	1179	1.764	20.88	290	0.356	0.248	5.27
Dozan, Balochistan	BOLAN-9	2089	1.194	0.333	7.94	0.126	1098	1.940	19.77	169	0.271	0.240	7.12
Dozan, Balochistan	BOLAN-10	2287	1.391	0.451	13.29	0.139	1554	2.461	13.14	309	0.425	0.299	9.14
Mari nala, Jammu	JAMM-1	2273	0.201	0.433	4.01	0.067	1048	0.224	11.44	73	0.059	0.034	1.58
Mari nala, Jammu	JAMM-2	5568	1.621	1.639	6.13	0.131	3253	1.330	115.8	550	0.863	0.195	4.02
Mari nala, Jammu	JAMM-3	2672	0.504	0.472	2.26	0.069	825	0.305	10.09	90	0.110	0.044	1.46
Mari nala, Jammu	JAMM-4	2535	0.243	0.497	2.72	0.082	724	0.294	8.05	79	0.094	0.034	1.37
Mari nala, Jammu	JAMM-5	2582	3.948	0.345	2.34	0.104	476	2.527	8.91	282	0.615	0.396	1.28
Jangleghari, Jammu	JAMM-6	4662	0.790	0.745	3.02	0.089	1144	0.559	12.34	219	0.335	0.105	2.96
Jangleghari, Jammu	JAMM-7	3903	0.293	0.635	3.12	0.086	1321	0.260	17.70	285	0.291	0.073	4.08
Jangleghari, Jammu	JAMM-8	5326	9.827	0.423	3.68	0.114	689	5.880	7.39	235	0.183	0.590	3.72
Jangleghari, Jammu	JAMM-9	5251	2.345	0.858	4.22	0.117	1698	1.649	65.81	1388	0.707	0.272	6.15
Jangleghari, Jammu	JAMM-10	2290	0.346	0.374	2.58	0.082	881	0.285	11.32	124	0.099	0.058	0.79

Appendix 6.3: Elemental concentrations for black chert samples from Sakesar Limestone, Salt Range (parts per million)

Location	Sample	Al	Ce	Co	Cr	Eu	Fe	La	Mn	Na	Sc	Sm	V
Nammal Gorge, Salt Range	SRNG-1	2133	0.981	0.388	14.44	0.122	914	0.928	11.53	659	0.162	0.193	9.87
Nammal Gorge, Salt Range	SRNG-2	2517	0.900	0.539	21.97	0.097	1442	0.874	9.84	477	0.215	0.181	21.00
Nammal Gorge, Salt Range	SRNG-3	2282	0.771	0.453	15.13	0.103	1129	0.840	10.47	500	0.152	0.182	11.90
Nammal Gorge, Salt Range	SRNG-4	2433	0.925	0.576	24.86	0.117	1801	0.958	12.46	377	0.267	0.187	38.88
Nammal Gorge, Salt Range	SRNG-5	2204	1.063	0.437	16.90	0.117	1192	1.229	10.25	338	0.202	0.267	18.87
Nammal Gorge, Salt Range	SRNG-6	2259	0.795	0.486	16.80	0.092	1166	0.913	14.48	482	0.197	0.157	19.38
Nammal Gorge, Salt Range	SRNG-7	2474	0.912	0.518	16.90	0.074	1409	0.907	10.89	421	0.192	0.160	20.11
Nammal Gorge, Salt Range	SRNG-8	2333	0.886	0.417	13.29	0.090	678	0.879	7.25	339	0.217	0.182	17.06
Nammal Gorge, Salt Range	SRNG-9	2270	1.041	0.518	17.20	0.088	1085	1.061	14.99	431	0.241	0.186	18.95
Nammal Gorge, Salt Range	SRNG-10	2179	0.645	0.661	26.57	0.092	2999	0.875	31.91	667	0.176	0.198	10.91
Buri Khel, Salt Range	SRBK-6	2334	0.753	0.535	19.57	0.101	1587	0.678	18.73	322	0.184	0.146	12.53
Buri Khel, Salt Range	SRBK-7	2200	1.002	0.476	14.61	0.129	913	0.658	8.58	349	0.192	0.149	12.07
Buri Khel, Salt Range	SRBK-8	2386	1.108	0.423	14.44	0.113	913	0.799	9.51	333	0.214	0.200	11.69

Appendix 6.4: Elemental concentrations for tan-gray chert artifacts from Harappa and Nagwada (bottom row) (parts per million)

Figure 6.1 #	**Sample**	**Period**	**Trench**	**Al**	**Ce**	**Co**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**U**	**V**
5	H98/8482-13	1	39	2044	2.338	1.003	0.141	1748	1.170	11.01	644	0.268	7.52	23.01
12	H96/7531-4	1	39	1914	3.021	0.513	0.126	1617	0.837	13.25	435	0.220	11.18	13.73
11	H96/7500-30	1	39	2429	0.548	0.375	0.101	610	0.494	4.26	689	0.073	0.93	7.04
15	H98/8429-24	2	39	8678	1.320	0.430	0.097	1228	0.714	33.43	439	0.231	3.34	37.24
13	H2000/9984-12	2	39	1841	0.876	0.507	0.119	994	0.829	65.98	278	0.193	2.14	5.36
14	H98/8417-1	2/3	39	1779	2.300	0.533	0.101	916	0.593	7.88	823	0.173	10.08	9.29
6	H2000/2125-17	3A	54	2054	3.038	0.879	0.076	1412	0.922	23.85	957	0.137	12.72	18.95
7	H2000/2300-24	3A	54	1794	4.124	0.419	0.140	737	1.048	19.25	583	0.169	18.06	7.74
9	H2000/2312-27	3A	54	1702	1.938	0.427	0.137	891	0.721	7.90	718	0.132	7.60	9.08
8	H97/7781-46	3B	42	2103	1.696	0.540	0.128	1030	0.775	21.07	374	0.239	5.31	5.44
10	H97/7778-17	3B	42	1853	1.754	0.375	0.073	769	0.503	8.01	520	0.139	8.04	6.60
1	H2001/2939-27	3B	54	1841	8.355	0.680	0.127	1142	1.505	7.64	617	0.162	30.94	31.91
2	H2001/2920-77	3B	54	1664	0.774	0.390	0.117	513	0.704	25.68	448	0.159	1.80	4.56
3	H2001/2920-76	3B	54	1746	6.947	0.429	0.099	644	1.398	3.34	699	0.165	28.08	14.81
4	H2001/2943-7	3B	54	1735	3.578	0.422	0.110	818	0.912	4.08	889	0.163	14.53	9.37
Fig. 6.1	NGW	Harappan	n/a	8342	2.884	0.391	0.110	902	1.102	67.15	451	0.200	10.00	46.32

Appendix 6.5: Elemental concentrations for tan-gray chert samples from four Rohri Hills locations (parts per million)

Location	Sample	Al	Ce	Co	Eu	Fe	La	Mn	Na	Sc	U	V
Adam Sultan	RHAS-1	2153	1.499	0.391	0.128	799	0.533	5.08	656	0.324	2.78	7.34
Adam Sultan	RHAS-2	2186	1.003	0.461	0.126	1164	0.925	12.23	579	0.320	2.17	6.95
Adam Sultan	RHAS-3	2150	1.198	0.437	0.061	1280	0.479	7.94	619	0.311	2.84	8.40
Adam Sultan	RHAS-4	2356	1.116	0.514	0.150	1584	1.183	15.25	759	0.364	1.96	9.31
Adam Sultan	RHAS-5	2228	1.051	0.455	0.080	1099	0.506	6.78	654	0.309	3.02	8.09
Kot Diji	RHKD-1	2136	2.110	1.158	0.129	1588	1.076	72.28	292	0.325	4.32	10.88
Kot Diji	RHKD-2	2213	1.938	0.477	0.136	933	1.173	23.57	413	0.521	2.50	13.20
Kot Diji	RHKD-3	2532	1.286	2.019	0.103	5160	0.882	60.20	367	0.474	3.81	36.91
Kot Diji	RHKD-4	1996	0.460	0.971	0.091	2517	0.541	12.77	544	0.366	1.69	19.19
Kot Diji	RHKD-5	2357	2.172	0.967	0.155	1786	1.298	41.37	538	0.449	1.71	12.66
Rohri	RHR-1	1737	0.777	0.355	0.116	1142	0.514	10.44	427	0.135	3.09	8.50
Rohri	RHR-2	1622	5.648	0.469	0.076	1651	1.127	10.55	266	0.171	23.01	8.64
Rohri	RHR-3	1721	1.509	0.535	0.116	2172	0.818	11.52	185	0.136	5.60	20.30
Rohri	RHR-4	1892	1.280	0.523	0.093	2161	0.706	15.31	271	0.235	5.22	9.44
Rohri	RHR-5	1572	1.279	0.493	0.084	1134	0.628	9.06	504	0.160	4.13	11.02
Kandarki	RHK-1	1946	1.632	0.677	0.083	2009	0.448	22.88	225	0.244	6.47	9.79
Kandarki	RHK-2	2071	1.643	0.762	0.072	2742	0.554	20.99	207	0.278	7.52	10.94
Kandarki	RHK-3	2024	1.514	0.793	0.097	2812	0.503	28.13	257	0.268	6.37	10.62
Kandarki	RHK-4	1979	1.349	0.892	0.101	3812	0.692	45.91	196	0.206	5.31	9.37
Kandarki	RHK-5	2041	2.853	0.663	0.071	2057	0.819	16.86	229	0.246	13.12	10.84

Appendix 6.6: Elemental concentrations for tan-gray chert samples from Balochistan, the NWFP and the Punjab (parts per million)

Location	Sample	Al	Ce	Co	Eu	Fe	La	Mn	Na	Sc	U	V
Balochistan - Kalat - Gunga	Aub138-1	12924	0.349	0.415	0.081	1046	0.315	40.15	218	0.073	0.28	6.86
Balochistan - Kalat - Gunga	Aub138-2	13274	0.348	0.316	0.087	628	0.334	15.62	217	0.054	0.23	4.12
Balochistan - Kalat - Gunga	Aub138-3	2624	0.737	0.536	0.102	1223	1.294	7.18	322	0.203	0.45	1.49
Balochistan - Kalat - Gunga	Aub138-4	14108	0.580	0.527	0.110	1653	1.195	53.11	404	0.299	0.45	17.61
Balochistan - Kalat - Gunga	Aub138-5	32205	3.268	2.264	0.156	4191	2.974	248.34	1410	1.336	1.37	66.87
NWFP - Mohmand Agency	MMA-1	2221	2.839	0.702	0.104	1697	1.013	27.94	323	0.226	12.27	19.53
NWFP - Mohmand Agency	MMA-2	1678	2.520	0.466	0.109	890	1.063	33.91	189	0.171	11.61	14.65
NWFP - Mohmand Agency	MMA-3	1606	2.789	0.610	0.112	1286	1.015	34.32	176	0.158	11.01	14.12
NWFP - Mohmand Agency	MMA-4	363	2.412	0.425	0.242	1566	2.160	4.07	190	0.217	4.91	2.72
NWFP - Mohmand Agency	MMA-5	6738	1.099	0.369	0.127	925	1.260	85.85	141	0.169	2.00	23.73
NWFP - Mohmand Agency	MMA-6	1569	1.933	0.381	0.130	732	1.124	16.96	136	0.161	4.72	5.75
NWFP - Mohmand Agency	MMA-7	1841	2.352	0.572	0.110	1616	0.778	22.61	175	0.127	9.72	16.09
NWFP - Mohmand Agency	MMA-8	1690	2.983	0.448	0.101	1124	1.045	29.59	217	0.188	10.65	21.79
Punjab - Salt Range - Buri Khel	SRBK-1	2145	1.043	0.420	0.174	1782	1.231	12.24	197	0.149	0.98	8.26
Punjab - Salt Range - Buri Khel	SRBK-2	1917	1.724	0.365	0.174	1436	2.008	14.28	159	0.230	1.02	6.22
Punjab - Salt Range - Buri Khel	SRBK-3	2390	0.599	0.428	0.121	1159	0.589	9.46	229	0.146	0.79	9.32
Punjab - Salt Range - Buri Khel	SRBK-4	2093	0.957	0.402	0.123	840	1.077	8.85	187	0.161	0.85	6.35
Punjab - Salt Range - Buri Khel	SRBK-5	1973	0.895	0.402	0.120	1323	0.926	11.09	152	0.140	0.73	6.15

Appendix 6.7: Standardized canonical discriminant function coefficients for figures in Chapter 6 generated using canonical discriminant analysis

Figure 6.12	*Function 1*	*Function 2*
Log Al	-1.79	-1.246
Log Ce	2.046	-3.226
Log Co	1.299	1.036
Log Cr	0.949	-0.693
Log Eu	0.496	0.569
Log La	-1.596	3.698
Log Mn	-0.733	-0.056
Log Sc	-0.312	0.007
Log V	0.82	0.339

Figure 6.17 A	*Function 1*	*Function 2*
Log Al	1.688	1.425
Log Ce	.953	-.993
Log Co	.546	-1.242
Log Eu	-.530	.256
Log Fe	.594	1.213
Log La	.289	-.905
Log Mn	-.933	.320
Log Na	.348	.735
Log Sc	-.285	.809
Log U	-1.321	1.738
Log V	-1.217	-2.230

Figure 6.17 B	*Function 1*	*Function 2*
Log Al	.142	1.559
Log Ce	-.401	.361
Log Co	-1.608	-.877
Log Eu	.204	.068
Log Fe	1.190	1.502
Log La	.125	-.635
Log Mn	.238	-.373
Log Na	.123	.604
Log Sc	-.865	-.064
Log U	1.095	.233
Log V	-.157	-1.386

Appendix 7.1: Type, context and CDA prediction information for the unfired steatite artifacts from Harappa analyzed for this study (*bead blanks)

Artifact (year/lot-record)	**Type**	**Mound / Area**	**Trench / Op.**	**Period**	**CDA predicted group membership (PGM)**			
					full set 1st PGM	**parent-rock** 1st & 2nd PGM	**11 dolomitic** 1st PGM	**regional dolomitic** 1st PGM
H87/33-02	F	Cemetery	Op. 1	3C	SB	SB / SKK	SB	Sherwan
H87/86-228	F	Cemetery	Op. 1	3C	SB	SB / JKK	SB	S.RAJ
H87/86-229	F	Cemetery	Op. 1	3C	SB	SB / JKK	SB	S.RAJ
H87/86-236	F	Cemetery	Op. 1	3C	SB	JKK / SB	SB	Sherwan
H87/237-86	F	Cemetery	Op. 1	S&D	SB	SB / ATM	SB	Sherwan
H88/340-24	F	E	Op. 3	S&D	PD	RKA / PD	PD	PD
H89/1018-13	D	AB / E	53	S&D	SKK	SKK / SB	SKK	Sherwan
H89/1121-5	A	E	52	S&D	SKK	SKK / SC	SKK	Sherwan
H2000/2230-14	C	E	54	3B	SB	SB / RSA	SB	Sherwan
H2000/2230-15	C	E	54	3B	SB	SB / LKPD	LKPD	LKPD
H2000/2230-16	C	E	54	3B	JAMPT	JAMPT / RSA	JAMPT	JAMPT
H2000/2230-17	B	E	54	3B	JAMPT	JAMPT / SB	JAMPT	Sherwan
H2000/2301-176*	B	E	54	3A	SB	JAMPT / SB	JAMPT	Sherwan
H2000/2301-177*	B	E	54	3A	JAMPT	JAMPT / SB	JAMPT	JAMPT
H2001/2373-10	C	E	54	3B	RSA	RSA / SB	SKK	Sherwan
H2000/2753-17	E	E	55	3C	SB	SB / PD	PD	PD
H2000/2774-14	G	E	55	3C	SKK	SC / SKK	SC	Sherwan
H2000/2774-15	C	E	55	3C	SB	PD / SKK	SKK	PD
H2000/2789-30	C	E	55	3C	SKK	SKK / SB	SKK	Sherwan
H2000/2880-16	D	E	55	3C	ATM	ATM / RSA	SKK	JAMPT
H2001/2913-12	E	E	57	3B	SKK	SKK / SB	SKK	Sherwan
H2001/2920-7	C	E	57	S&D	SB	SB / SKK	SKK	Sherwan
H2001/2922-6	A	E	57	S&D	SB	SB / SKK	SB	Sherwan
H2001/2939-25	G	E	57	3B	LKPD	JAMPT / BESH	LKPD	LKPD
H90/3030-55	E	E	58	S&D	JAMPT	JAMPT / RSA	JAMPT	Sherwan
H90/3068-50	A	E	58	S&D	SB	SB / RSA	SB	PD
H90/3290-17	D	E	59	S&D	SB	SB / SKK	SB	Sherwan
H93/3534-13	F	E	2	S&D	SKK	RSA / SB	LKPD	Sherwan
H93/3710-16	F	E	3	3C	SB	SB / SKK	SB	Sherwan
H93/3710-70	F	E	3	3C	SB	JKK / SB	LKPD	LKPD
H93/3808-52	A	E	5	S&D	SB	SB / SKK	SKK	Sherwan
H93/3869-24	A	E	7	3C	SB	PD / SB	SKK	PD
H95/4453-22	D	E	11	S&D	SB	SB / SKK	SB	Sherwan
H95/4613-42	A	ET	10	3B	SB	SKK / SB	SKK	Sherwan
H95/4615-94	A	ET	10	3C	SB	SKK / SB	SKK	Sherwan

Appendix 7.1 (cont.): Type, context and CDA prediction information for the unfired steatite artifacts from Harappa analyzed for this study (*unfinished seal)

Artifact (year/lot-record)	**Type**	**Mound / Area**	**Trench / Op.**	**Period**	**CDA predicted group membership (PGM)**			
					full set 1st PGM	**parent-rock** 1st & 2nd PGM	**11 dolomitic** 1st PGM	**regional dolomitic** 1st PGM
H95/4723-2	B	ET	19	3C	SB	LKPD / RDP	LKPD	LKPD
H95/4726-101	A	ET	19	3C	LKPD	SB / PD	SB	PD
H95/4746-7	A	ET	19	3C	SB	SB / PD	SB	PD
H95/4751-8	E	ET	19	3C	SB	LKPD / ATM	SKK	Sherwan
H95/4919-62	D	ET	28	3C	ATM	RDP / SC	RDP	Jhunjhunu
H95/4950-4	A	ET	28	3C	RDP	SB / SKK	SKK	Sherwan
H95/4954-18	E	ET	28	3C	SB	SB / SKK	SKK	Sherwan
H95/4961-176	A	ET	28	3C	SB	SB / SKK	SKK	Sherwan
H94/5135-34	E	E	7 / 8	3C	SB	SB / SKK	SB	Sherwan
H95/5184-1	A	E	7 / 8	3C	SB	SB / SKK	SB	Sherwan
H95/5713-145	C	ET	32	S&D	SB	SB / PD	SB	Sherwan
H95/5734-31	C	ET	32	3C	SB	PD / SB	PD	PD
H95/5747-125	B	ET	32	3C	PD	SB / SKK	SB	Sherwan
H95/5749-97	C	ET	32	3C	SB	RSA / SB	SKK	Sherwan
H95/5759-25	E	ET	32	3C	SB	SB / PD	SB	PD
H95/5763-19	A	ET	32	3C	SB	SB / SKK	SB	Sherwan
H95/5802-5	A	ET	28	3C	SB	LKPD / BESH	LKPD	LKPD
H95/5803-25	B	ET	28	3C	LKPD	LKPD / BESH	LKPD	LKPD
H95/5820-11a	A	ET	28	3C	LKPD	PD / SB	PD	PD
H96/5837-18	B	ET	28	3C	PD	SB / LKPD	SB	LKPD
H96/6218-8	C	ET	35	S&D	LKPD	SKK / PD	SKK	PD
H96/6219-44	D	ET	35	S&D	SB	SB / LKPD	SB	Sherwan
H96/6234-2	C	ET	35	S&D	SB	SB / SKK	SB	Sherwan
H96/6257-21	A	ET	35	3C	SB	SB / SKK	SKK	Sherwan
H95/6509-97	B	E / ET	11	2	SB	JAMPT / RSA	JAMPT	JAMPT
H96/7105-8	A	E	36	3C	JAMPT	SKK / SB	SKK	Sherwan
H96/7106-27	G	E	36	3C	SKK	LKPD / RDP	LKPD	LKPD
H96/7118-9	A	E	36	3C	LKPD	LKPD / BESH	LKPD	LKPD
H96/7153-14	D	E	36	S&D	LKPD	SB / SKK	SB	Sherwan
H96/7156-14	G	E	36	3C	SB	SB / LKPD	SB	Sherwan
H96/7239-26	A	F	37	3C	SB	SB / SKK	SB	Sherwan
H96/7256-43	B	F	37	3B	SB	SKK / SB	SKK	Sherwan
H96/7257-46*	B	F	37	3B	SKK	PD / SB	PD	PD
H96/7333-22	A	AB	38	5	PD	SC / SC	SC	Sherwan
H96/7358-11	A	AB	38	5	SC	LKPD / SKK	LKPD	LKPD

Appendix 7.1 (cont.): Type, context and CDA prediction information for the unfired steatite artifacts from Harappa analyzed for this study (*bead)								
Artifact (year/lot-record)	**Type**	**Mound / Area**	**Trench / Op.**	**Period**	**CDA predicted group membership (PGM)**			
					full set 1st PGM	**parent-rock** 1st & 2nd PGM	**11 dolomitic** 1st PGM	**regional dolomitic** 1st PGM
H96/7401-63	F	AB	39	S&D	SC	SC / RDP	SC	Sherwan
H96/7410-1	E	AB	39	2/3A	SKK	SKK / SB	SKK	Sherwan
H96/7410-2	E	AB	39	2/3A	SKK	SKK / SB	SKK	Sherwan
H96/7414-46	A	AB	39	2	SC	SC / SKK	SC	Sherwan
H96/7414-47	A	AB	39	2	JAMPT	JAMPT / LKPD	JAMPT	JAMPT
H96/7467-658*	A	AB	39	S&D	SKK	SB / JJG	ATM	S.RAJ
H96/7467-790	A	AB	39	S&D	RSA	RDA / SKK	SKK	Sherwan
H96/7531-16	A	AB	39	1	ATM	ATM / SB	ATM	Sherwan
H97/7619-3	C	F	41	3C	SB	SB / LKPD	SB	Sherwan
H99/7636-8	E	F	41	3C	JJK	JKK / ATM	RSA	Jhunjhunu
H99/7637-32	G	F	41	3C	JJK	JKK / RDP	LKPD	Jhunjhunu
H99/7638-1	G	F	41	3C	JJK	JKK / ATM	SB	Sherwan
H99/7649-42	A	F	41	3C	SB	SB / SKK	SB	Sherwan
H97/7780-10	E	AB	42	3B	SC	SC / SC	SB	Sherwan
H97/7780-8	A	AB	42	3B	SC	SC / SC	SC	Sherwan
H97/7780-9	A	AB	42	3B	SB	SB / SKK	SB	Sherwan
H97/7784-156	A	AB	42	3A	SKK	SKK / SC	SKK	Sherwan
H97/7784-157	F	AB	42	3A	RSA	RSA / LKPD	LKPD	LKPD
H97/7784-158	A	AB	42	3A	LKPD	LKPD / SB	LKPD	LKPD
H97/7784-159	A	AB	42	3A	SC	SC / SKK	SKK	Sherwan
H97/7784-16	A	AB	42	3A	RSA	RDA / SKK	RSA	Sherwan
H97/7784-17	A	AB	42	3A	JAMPT	JAMPT / SKK	SKK	JAMPT
H97/7784-18	A	AB	42	3A	USK	USK / SKK	USK	Uttaranchal
H97/7784-19	A	AB	42	3A	SC	SC / SKK	SC	Sherwan
H97/7784-20	A	AB	42	3A	USK	USK / SKK	USK	Sherwan
H97/7784-21	B	AB	42	3A	SB	SB / SKK	SB	Sherwan
H97/7784-22	C	AB	42	3A	JAMPT	JAMPT / SB	JAMPT	JAMPT
H97/7784-23	C	AB	42	3A	SB	SB / SKK	SKK	Sherwan
H97/7784-24	C	AB	42	3A	SKK	SKK / UB	SKK	Sherwan
H97/7784-25	A	AB	42	3A	JAMPT	JAMPT / SKK	SKK	JAMPT
H97/7784-27	A	AB	42	3A	LBW1	LBW1 /LBW2	-	-
H97/7784-28	B	AB	42	3A	SB	SB / SKK	SB	Sherwan
H97/7784-29	B	AB	42	3A	SC	LKPD / SC	SC	JAMPT
H97/7784-30	E	AB	42	3A	SB	SB / SKK	SKK	Sherwan
H97/7784-31	F	AB	42	3A	SC	SC / RDP	SC	LKPD

Appendix 7.1 (cont.): Type, context and CDA prediction information for the unfired steatite artifacts from Harappa analyzed for this study (*wig)

Artifact (year/lot-record)	**Type**	**Mound / Area**	**Trench / Op.**	**Period**	**CDA predicted group membership (PGM)**			
					full set 1st PGM	**parent-rock** 1st & 2nd PGM	**11 dolomitic** 1st PGM	**regional dolomitic** 1st PGM
H99/7794-3	B	AB	42	3C	SB	SB / LKPD	SB	Sherwan
H98/8342-3	F	AB	39	3C	SC	SB / LKPD	SB	Sherwan
H98/8355-2	A	AB	39	3B	SB	SC / SKK	SC	Sherwan
H98/8364-5	F	AB	39	3B	SB	SB / SKK	SKK	Sherwan
H98/8407-39	E	AB	39	2	RSA	SB / SC	SB	Sherwan
H98/8407-40	A	AB	39	2	SC	RSA / USK	RDP	Uttaranchal
H98/8410-12	A	AB	39	2	SC	SC / SKK	SC	Sherwan
H98/8486-50	A	AB	39	2	SKK	SC / SKK	SC	Sherwan
H98/8487-32	E	AB	39	2	JAMPT	SKK / SC	SKK	Sherwan
H98/8487-33	A	AB	39	2	PD	JAMPT / USK	JAMPT	JAMPT
H99/8490-103	B	AB	39	2	SC	PD / SKK	PD	PD
H99/8492-229	E	AB	39	2	SKK	SC / SKK	SC	Sherwan
H99/8497-3	E	AB	39	2	LKPD	SKK / SC	SKK	Sherwan
H98/8668-2*	E	F	43	3C	KOT	KOT / ZTT	-	-
H99/8760-77	F	F	43	3C	ATM	ATM / JKK	ANB	Jhunjhunu
H99/8956-1	A	AB	39	2	JAMPT	JAMPT / USK	SKK	Sherwan
H2000/8983-44	E	AB	39	2	LKPD	LKPD / SC	SC	Sherwan
H2000/8992-1	E	AB	39	2	JAMPT	JAMPT / RSA	JAMPT	JAMPT
H2000/8997-4	A	AB	39	2	JAMPT	JAMPT / USK	JAMPT	JAMPT
H2000/9442-2	E	AB	39	3B	SC	UB / SC	SC	Sherwan
H2000/9443-6	A	AB	39	3B	SKK	SKK / SC	SKK	Sherwan
H2000/9443-7	B	AB	39	3B	JAMPT	JAMPT / RSA	JAMPT	JAMPT
H2000/9445-1	G	AB	39	3B	ANB	ANB / ATM	ANB	Jhunjhunu
H2000/9445-2	G	AB	39	3B	LKPD	LKPD / SC	SC	LKPD
H2000/9447-5	A	AB	39	3B	SKK	SKK / SC	SC	Sherwan
H2000/9514-93	E	AB	39	2	JAMPT	JAMPT / SB	SB	JAMPT
H99/9737-22	A	F	43	3C	SB	SB / PD	SKK	PD
H99/9747-33	B	F	43	3C	SB	SKK / SB	SKK	Sherwan
H99/9756-16	A	F	43	3C	SB	SB / SKK	SB	Sherwan
H99/9779-4	A	F	43	3C	SB	SB / LKPD	SB	Sherwan
H2000/9840-8	E	F	43	3C	SB	SB / SC	SB	Sherwan
H2000/9973-13	C	AB	39	2	JAMPT	JAMPT / RSA	JAMPT	JAMPT
H2000/11001-6	A	AB	39	1	JAMPT	JAMPT / RSA	JAMPT	JAMPT
H2001/11562-26	F	E	11	S&D	SB	ATM / SB	SB	Sherwan
H2001/11923-9	C	E	11	3C	SB	SB / PD	SB	Sherwan

Appendix 7.2: Steatite deposits in Pakistan and India sampled for this study (the name or code used on maps is in **bold**)

Region	*District / Agency*	*Deposit*	*Source code*	*Coordinates*	*Parent-Rock*
Balochistan	Las Bela	Wayaro 1 (Duddo mine)	LBW1	≈ N 26° 02', E 66° 39'	Ultramafic
Balochistan	Las Bela	Wayaro 2 (Thaddi mine)	LBW2	≈ N 26° 00', E 66° 37'	Ultramafic
Balochistan	Zhob	Urgasai Nasir, Muslimbagh Ophiolite	ZUN	≈ N 30° 52', E 67° 39'	Ultramafic
Balochistan	Zhob	Takhahen, Muslimbagh Ophiolite	ZTAK	≈ N 30° 43', E 67° 52'	Ultramafic
Balochistan	Zhob	Tor Tangi, Muslimbagh Ophiolite	ZTT	≈ N 30° 56', E 67° 49'	Ultramafic
F.A.T.A.	Kurram	Safed Koh (Parachinar-Daradar)	PD	≈ N 33° 57', E 70° 14'	Dolomite
F.A.T.A.	Mohmand	Sakhakot-Qila Ophiolite (Kot)	KOT & Kot (MP)	≈ N 34° 27', E 71° 43'	Ultramafic
F.A.T.A.	Khyber	Landi Kotal (Prang Dera)	LKPD	≈ N 34° 00', E 71° 05'	Dolomite
N.W.F.P.	Swat	Tangir mine (Besham-Derai area)	BESH	≈ N 35° 55', E 72° 50'	Dolomite
N.W.F.P.	Hazara	Sherwan - Khanda Khu	SKK	≈ N 34° 11', E 73° 03'	Dolomite
N.W.F.P.	Hazara	Sherwan - Bandi	SB	≈ N 34° 12', E 73° 02'	Dolomite
N.W.F.P.	Hazara	Sherwan - Chelethar	SC	≈ N 34° 12', E 73° 02' 30"	Dolomite
N.W.F.P.	Chitral	near Tar village, Shi Shi Valley	CHT	≈ N 35° 43', E 71° 57'	Ultramafic
Jammu	Udhampur	Painthal	JAMPT	N 32° 59.695, E 74° 59.097	Dolomite
Uttaranchal	Bageshwar	Chatikhet to Dungri to Kanda	UB	N 29° 52.286, E 79° 51.198	Dolomite
Uttaranchal	Bageshwar	Saling	US	N 30° 01.086, E 79° 56.742	Dolomite
Uttaranchal	Bageshwar	Shishi Khani	USK	N 29° 48.678, E 79° 46.374	Dolomite
Gujarat	Sarbarkantha	Dev Mori – Bhiloda & Kundol	DMB & DMK	N 23° 36.276, E 73° 23.050	Ultramafic
Gujarat	Panchmahal	Gandhra	GPM	N 22° 27.449, E 73° 41.372	Dolomite

Appendix 7.2 (cont.): Steatite deposits in Pakistan and India sampled for this study (the name or code used on maps is in **bold**)					
Region	*District / Agency*	*Deposit*	*Source code*	*Coordinates*	*Parent-Rock*
Rajasthan	Alwar	Nangalhari-Bairaswas	ANB	N 27° 27.003, E 76° 24.209	Dolomite
Rajasthan	Alwar	Samra	ASM	N 27° 11.254, E 76° 13.929	Dolomite
Rajasthan	Alwar	Teori	ATM	N 27° 24.070, E 76° 08.880	Dolomite
Rajasthan	Jaipur	Degota	DGT	N 27° 06.122, E 76° 14.995	Dolomite
Rajasthan	Jhunjhunu	Chirani-ki-Dhani	JJC	N 28° 00.643, E 75° 48.522	Dolomite
Rajasthan	Jhunjhunu	Gurda	JJG	N 27° 48.847, E 75° 38.419	Dolomite
Rajasthan	Jhunjhunu	Kho	JJK	N 27° 47.218, E 75° 37.948	Dolomite
Rajasthan	Dungarpur	Deola	RDP	N 23° 53.762, E 74° 21.052	Dolomite
Rajasthan	Dungarpur	Manpur	RMP	N 23° 51.328, E 73° 45.714	Ultramafic
Rajasthan	Dungarpur	Shala Shah Thana	RST	N 24° 03.222, E 73° 40.115	Ultramafic
Rajasthan	Rajsamand	Karoli	RKA	N 24° 51.731, E 73° 45.499	Dolomite
Rajasthan	Rajsamand	Rabcha	RRA	N 24° 53.786, E 73° 47.074	Dolomite
Rajasthan	Udaipur	Dev Pura	RDV	N 24° 18.182, E 73° 46.715	Dolomite
Rajasthan	Udaipur	Kali Ghadi mine	RKG	≈ N 24° 07', E 73° 40'	Ultramafic
Rajasthan	Udaipur	Rishab-der	RRD	≈ N 24° 02', E 73° 38'	Ultramafic
Rajasthan	Udaipur	near Salumbar	RSA	N 24° 07.204, E 74° 07.356	Dolomite
Rajasthan	Udaipur	Shiv Bola mine	RSB	≈ N 24° 03', E 73° 38'	Ultramafic
Rajasthan	Udaipur	Khadi Ghati mine	RSH	≈ N 23° 59', E 73° 47'	Ultramafic

Appendix 7.3: INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
ANB-01	10838	3.9488	10.590	0.05794	11394	0.11851	19.309	8070.88	0.0914	14.730	51.540
ANB-02	3132	7.3863	18.501	0.09754	16045	0.45252	29.321	1535.31	1.0496	27.033	41.686
ANB-03	8829	5.6125	27.046	0.09216	13640	0.73486	29.457	6347.02	0.8313	34.387	27.745
ANB-04	7410	5.8687	14.154	0.10109	13597	0.66108	24.943	5285.76	0.3912	28.835	37.634
ANB-05	3091	3.4451	26.685	0.43534	11673	7.81245	25.551	74367.16	0.3194	14.189	20.415
ANB-06	22469	0.3813	2.237	0.30380	70	0.48679	17.283	18026.28	0.0108	11.905	14.381
ANB-07	4773	4.4095	7.093	0.08936	14249	0.18589	26.341	3288.62	0.3825	13.995	45.756
ANB-08	6040	5.0426	13.260	0.09656	14669	0.35191	23.527	5162.58	0.2676	14.967	47.480
ANB-09	2328	4.5184	6.484	0.10308	15652	0.12945	30.896	1238.02	0.7509	12.448	46.318
ANB-10	1749	6.2960	2.247	0.08499	15789	0.25353	26.296	613.34	0.2643	14.709	45.772
ASM-01	5041	62.0628	2.915	0.23708	38576	3.89395	119.895	607.59	6.1815	21.671	37.106
ASM-02	6884	82.9666	2.914	0.06382	37394	0.12002	53.078	900.75	2.4121	15.407	33.901
ASM-03	6102	52.2559	1.932	0.89868	38991	16.74099	80.896	656.70	7.9921	27.205	12.812
ASM-04	2822	51.9297	2.884	0.26342	29682	0.06561	49.394	473.77	1.4676	11.472	68.865
ASM-05	41383	72.0259	49.150	0.21734	65274	0.44792	218.157	660.62	29.7642	166.489	137.797
ASM-06	2960	53.3159	3.713	0.31987	30370	0.11255	55.553	459.96	1.4998	12.165	70.003
ASM-07	4970	66.6679	3.141	0.27488	41526	0.21308	80.665	586.59	5.0374	23.166	87.085
ASM-08	33971	20.3045	5.084	0.32132	41635	4.06409	97.341	14805.97	4.1106	26.794	84.438

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
ASM-09	7119	82.8355	3.964	0.13809	38061	0.16251	55.816	974.15	3.1366	14.850	84.884
ASM-10	65164	22.2235	3.077	1.60397	38030	2.13848	124.022	25641.84	25.3054	72.457	142.649
ATM-01	1677	6.2143	2.813	0.07908	20473	0.22484	25.001	390.68	0.3548	5.183	6.095
ATM-02	5810	2.1351	14.640	0.09001	32356	0.31447	41.247	3644.99	0.6938	7.196	6.275
ATM-03	5159	14.9285	10.380	0.07973	28458	0.27459	22.405	3328.93	0.6876	12.313	3.800
ATM-04	3889	1.5232	15.730	0.05143	31239	0.16566	35.516	2273.82	0.7773	7.150	22.180
ATM-05	6721	3.3619	17.187	0.04968	26144	0.29461	41.465	3225.97	0.5200	9.717	32.150
ATM-06	5730	2.6302	18.141	0.07411	26532	0.14313	38.372	3462.39	0.7080	7.576	29.552
ATM-07	9607	1.5114	5.150	0.17968	20752	0.39987	30.897	6358.00	3.2441	25.090	35.433
ATM-08	2768	2.8818	15.250	0.32287	21113	4.71459	25.715	1228.56	1.3072	4.128	98.035
ATM-09	3756	2.9824	19.677	0.06657	23758	0.22930	33.263	1789.40	0.5454	6.506	139.586
ATM-10	8376	1.9656	21.103	0.09169	33995	0.27174	47.483	5491.45	0.6311	12.428	52.167
BESH-01	2239	8.1390	6.345	0.05292	14530	0.22150	82.440	219.30	0.1118	4.788	568.600
BESH-02	2257	6.9080	2.858	0.05239	11990	0.28980	87.760	179.20	0.1890	5.007	434.800
BESH-03	3139	2.0640	2.489	0.04839	8117	0.32120	48.530	139.20	0.0947	2.744	531.900
BESH-04	71670	11.0200	8.560	0.04323	44940	0.32870	487.600	296.50	0.5624	55.650	1296.000
BESH-05	3643	1.8650	1.965	0.03865	2861	0.18330	9.407	279.70	0.2165	2.726	43.000
BESH-06	3445	1.4640	1.382	0.03483	5227	0.16170	54.120	165.70	0.0633	3.581	385.800

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
BESH-07	2368	5.7100	1.384	0.03668	8537	0.13520	92.560	205.70	0.0335	4.423	375.700
BESH-08	288100	8.6170	1.714	0.89020	34990	0.02025	1818.000	602.30	0.4421	192.800	654.700
BESH-09	6294	1.5730	2.235	0.44240	6020	0.37730	757.000	508.60	0.0257	17.760	364.000
BESH-10	12240	1.3000	0.509	0.41680	5574	0.04844	177.900	526.20	0.0692	11.680	270.900
BESH-11	101184	20.2194	208.043	1.25781	43280	4.92390	713.736	151.10	25.0873	211.205	22.748
BESH-12	4202	7.0086	2.595	0.22313	15384	0.03995	175.395	204.52	0.0848	2.869	152.584
BESH-13	8075	4.7009	1.767	0.19409	11920	0.04019	118.327	191.78	1.1084	19.355	39.338
BESH-14	5199	5.4254	1.195	0.19123	18031	0.05475	135.046	190.08	0.2133	5.153	103.612
BESH-15	1905	1.7992	1.573	0.23199	8265	0.03838	104.997	225.29	0.1364	2.502	98.001
BESH-16	94333	21.8023	305.652	1.85439	44065	8.45024	707.173	172.40	28.6916	210.017	24.870
BESH-17	30667	10.9718	12.519	0.29486	20318	1.03641	441.085	599.70	1.0251	27.116	56.984
BESH-18	1895	2.1192	1.475	0.25487	8601	0.02884	87.668	226.47	0.0918	2.295	100.799
BESH-19	71702	14.0866	2.197	0.28934	52650	0.23441	566.914	172.04	0.3568	47.622	191.391
BESH-20	10212	5.1084	4.361	0.24096	8159	0.27919	74.660	167.42	1.1110	17.091	35.978
CHT-01	106973	37.4111	252.490	0.08462	31397	0.27117	1283.800	229.00	13.5074	65.563	13.795
CHT-02	117172	24.4544	156.033	0.17549	16728	0.30203	896.089	4621.36	9.1946	33.072	23.148
CHT-03	101559	22.1545	274.141	0.10190	20277	0.36848	1155.188	1396.08	14.3497	28.129	16.565
CHT-04	1992	17.9343	1755.345	0.06929	62445	0.02929	163.860	942.54	1.7578	10.074	11.245

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
CHT-05	105750	20.1943	120.602	0.27555	19625	0.55821	939.388	611.05	9.7798	38.550	13.247
CHT-06	5938	116.4152	2884.070	0.08195	43116	0.43713	486.602	166.03	3.8576	24.764	15.172
CHT-07	4602	100.3270	2201.815	0.08196	41532	0.83485	513.342	185.47	4.4241	20.801	11.143
CHT-08	3309	95.8852	1084.921	0.21570	42565	1.35871	1069.746	136.54	6.9632	18.399	13.617
CHT-09	7353	118.8686	2890.156	0.19991	42785	0.38929	538.488	134.39	6.8112	49.121	16.443
CHT-10	10114	101.4568	2551.579	0.08495	35019	0.81213	502.177	136.86	3.2900	27.145	12.231
CHT-11	107126	79.1107	130.300	0.06972	57412	0.02540	995.937	154.67	2.2985	9.900	20.765
CHT-12	4467	94.7426	2246.069	0.08479	39322	0.43779	470.692	161.75	3.3723	22.757	12.124
CHT-13	107120	47.0076	854.304	0.09972	30458	0.77108	1113.708	222.22	25.6847	73.995	16.853
CHT-14	114231	39.0685	585.932	0.13376	30470	1.82156	1172.146	179.60	23.9586	77.056	16.036
CHT-15	107996	17.6785	93.941	0.14288	17011	0.13516	981.748	4771.21	6.0683	23.332	15.953
CHT-16	7886	52.5927	1001.070	0.05159	36690	0.15301	289.861	131.79	5.6678	29.849	8.673
CHT-17	5249	92.6355	3230.896	0.19414	49392	0.24402	501.981	149.64	4.1732	32.134	14.290
CHT-18	6080	108.8336	2335.358	0.31449	41961	0.39644	523.869	130.70	6.6138	34.360	15.347
CHT-19	5240	96.6386	3822.270	0.21664	48799	0.38621	519.646	138.69	3.6297	29.835	24.565
CHT-20	1521	27.1111	399.325	0.22573	17480	0.02248	147.894	203.58	2.3574	4.388	8.673
DGT-01	10669	6.0233	13.351	0.18205	8559	0.28125	21.665	226.72	4.3521	15.589	7.858
DGT-02	6703	7.6544	4.305	0.11760	13183	0.11123	38.973	237.82	2.5701	12.083	7.886

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
DGT-03	9187	6.4690	11.263	0.10631	6614	0.19383	23.168	206.25	2.3182	12.165	6.900
DGT-04	16087	14.8073	10.463	0.08876	17581	0.28503	43.289	235.76	5.5005	28.033	9.310
DGT-05	7106	4.6700	7.774	0.15633	3893	0.29221	21.524	219.67	1.8603	10.558	6.297
DGT-06	8457	4.8610	7.840	0.09832	4156	0.04864	13.788	222.64	2.0799	13.015	3.478
DGT-07	3448	9.2071	3.588	0.11251	14814	0.14959	44.825	312.87	1.1908	6.467	7.178
DGT-08	2883	6.9818	0.829	0.10871	6783	0.03726	18.495	265.13	1.0948	5.572	6.274
DGT-09	10254	15.5073	11.945	0.12889	17041	0.23820	33.675	250.97	3.7338	16.161	48.875
DGT-10	9762	5.0405	12.938	0.17957	4672	2.44249	9.477	240.51	3.0705	13.624	55.805
DMB-01	9513	84.7546	1426.757	0.14157	27827	0.14541	126.587	137.19	4.7140	20.145	84.789
DMB-02	7540	86.5644	1286.542	0.09382	28275	0.13249	122.483	236.04	3.9437	18.922	83.137
DMK-01	9025	50.7741	941.290	0.06221	19443	0.03357	398.081	108.67	3.0674	24.211	9.745
DMK-02	3126	55.9530	923.911	0.10377	23669	0.10086	175.869	157.69	2.7086	12.054	10.730
DMK-03	1945	64.8495	187.698	0.08588	28092	0.04729	246.996	167.09	0.7702	3.661	23.205
DMK-04	7331	67.5889	1095.566	0.12478	29451	0.02708	276.361	140.55	1.4461	16.281	18.978
DMK-05	9726	72.9098	1291.936	0.08284	30920	0.03825	277.173	187.79	5.7345	22.016	11.968
DMK-06	6589	77.8280	1126.932	0.09159	32582	0.03555	257.156	159.30	5.2730	18.443	11.963
DMK-07	6328	60.0072	1370.227	0.11073	32866	0.05718	226.010	147.65	5.8568	23.149	11.444
DMK-08	5029	87.1290	1631.007	0.13266	30083	0.05934	278.276	157.09	3.1263	17.790	13.005

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
DMK-10	3828	96.9284	1628.703	0.08653	32379	0.04035	253.713	162.39	3.3557	15.465	12.120
DMK-11	6680	90.6609	1716.564	0.11786	37669	0.05292	310.524	175.81	5.1705	29.491	102.259
DMK-12	18079	74.7236	2491.719	0.09747	38212	0.07968	386.375	120.61	5.6655	38.142	100.534
DMK-13	6697	96.1327	1494.200	0.08630	33717	0.08049	319.308	161.22	4.7049	15.306	102.422
DMK-14	6098	90.6916	1671.748	0.08014	36766	0.07244	318.308	149.75	4.6683	29.821	57.390
DMK-15	7713	83.6133	1541.921	0.08714	35100	0.07953	238.198	183.59	6.0348	22.563	72.089
DMK-16	3225	55.6025	791.463	0.08320	19492	0.05119	137.389	88.17	2.5608	6.481	69.765
DMK-17	5706	92.1768	1170.556	0.06766	30559	0.07270	297.370	212.33	2.9652	13.617	82.295
DMK-18	76891	98.8970	3065.504	0.06562	63635	0.11517	872.518	150.57	10.1874	91.289	109.359
DMK-20	8093	84.8584	1796.771	0.10074	35358	0.15849	319.981	129.71	6.5988	29.382	93.062
GPM-01	5423	8.4175	10.122	0.50112	45689	1.11776	1304.832	204.77	1.5511	13.204	8.091
GPM-02	24289	23.1947	26.854	0.35009	23633	17.94244	50.918	263.98	1.3009	37.809	9.167
GPM-03	9627	24.8549	24.570	0.14107	19216	1.23550	36.125	218.12	0.4534	14.297	5.547
GPM-04	3752	24.0747	10.587	0.12255	18928	0.22539	118.464	218.97	0.3317	6.994	4.621
GPM-05	7668	19.3660	14.075	0.28667	20726	4.46669	37.266	210.07	0.4143	11.930	7.647
GPM-06	5999	15.6893	8.417	0.10437	17532	0.58996	29.731	192.49	0.3097	9.737	7.407
GPM-07	8133	19.3785	13.304	0.25141	21316	4.34528	36.563	206.06	0.4585	14.519	4.980
GPM-08	1498	18.5584	25.875	0.12068	29505	0.05865	54.423	285.49	0.0747	10.443	39.973

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
GPM-09	4279	19.2200	8.610	0.19906	36804	0.23435	147.245	360.61	1.1449	14.331	31.427
GPM-10	5561	36.8421	25.899	0.16076	29597	0.45556	54.699	353.48	0.5022	7.632	7.623
GPM-11	18993	14.8698	61.788	0.46786	26801	6.35172	56.388	205.27	0.9813	48.626	64.933
GPM-12	7446	19.5151	12.835	0.33685	21322	4.06235	42.238	198.83	0.4171	10.700	42.227
GPM-13	1781	8.3863	10.379	0.12722	19072	0.12013	51.999	205.65	0.9786	12.944	51.959
GPM-14	1335	12.6894	4.039	0.10503	21446	0.05999	74.570	196.98	0.0397	9.987	216.002
GPM-15	22140	28.7355	25.059	0.31456	24413	7.25684	123.649	197.34	1.1818	33.229	69.755
GPM-16	10669	22.1336	15.308	0.23140	20895	6.09588	37.484	218.02	0.4693	14.147	35.495
GPM-17	22519	8.5138	25.909	0.42990	27974	4.20658	69.799	186.57	2.2795	37.216	62.572
GPM-18	14257	22.9619	25.549	0.31974	22123	11.46318	36.009	239.07	0.6139	18.512	38.234
GPM-19	85546	45.6732	208.263	2.15307	61127	64.98015	226.230	283.90	6.8655	173.279	127.264
GPM-20	10051	13.7382	17.975	0.36369	22320	1.32386	40.080	225.71	1.3270	21.891	58.115
JAMPT-01	1379	0.8330	3.804	0.07126	9150	0.10014	12.848	189.04	0.0403	1.059	21.178
JAMPT-02	1247	8.2883	6.595	0.07072	38615	0.17226	21.009	179.33	0.0356	1.283	132.905
JAMPT-03	1499	0.5007	0.795	0.07731	14379	0.07150	34.591	234.90	0.0313	1.024	42.897
JAMPT-04	1237	0.7343	0.741	0.08361	17375	0.05548	11.869	144.93	0.0236	0.879	37.654
JAMPT-05	1008	0.6014	0.602	0.07076	15601	0.06094	9.419	162.48	0.0110	0.736	30.932
JAMPT-06	1312	0.6122	1.141	0.06523	13932	0.04025	13.107	173.56	0.0220	0.860	16.417

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
JAMPT-07	1075	0.4282	0.624	0.07321	6567	0.05699	7.349	155.13	0.0219	0.841	19.320
JAMPT-08	1156	0.4964	0.446	0.07473	14706	0.05947	8.836	165.15	0.0171	0.757	27.459
JAMPT-09	1174	0.4168	0.680	0.06992	5232	0.08573	8.023	177.25	0.0346	0.657	26.997
JAMPT-10	1334	0.3708	0.500	0.06937	9528	0.05464	6.995	180.79	0.0223	1.023	25.009
JAMPT-11	1093	0.2597	1.882	0.08931	5597	0.04213	5.976	168.91	0.0272	0.705	15.003
JAMPT-12	1144	0.2401	0.471	0.06716	7817	0.01537	6.731	183.36	0.0243	0.469	14.549
JAMPT-13	1145	0.2698	1.544	0.06486	4570	0.02788	6.138	159.50	0.0247	0.975	15.477
JAMPT-14	1136	0.2078	0.727	0.05722	9072	0.02466	7.328	164.36	0.0366	1.213	15.572
JAMPT-15	1461	0.6933	0.537	0.06947	13019	0.03613	9.810	360.55	0.0188	0.794	18.599
JAMPT-16	1117	0.2918	0.751	0.05119	4755	0.04360	6.677	197.60	0.0231	0.756	15.213
JAMPT-17	1157	0.2158	0.522	0.07858	7256	0.02260	6.683	155.56	0.0196	0.806	13.540
JAMPT-18	1309	0.5034	0.947	0.06830	15084	0.02816	10.079	207.54	0.0143	0.618	20.928
JAMPT-19	1252	0.5468	1.002	0.06902	14749	0.02474	11.595	172.46	0.0159	0.775	20.737
JAMPT-20	1261	0.5621	1.069	0.07926	10466	0.09022	77.548	199.55	0.0366	1.116	35.229
JJC-01	6990	0.1853	0.330	0.04307	44	0.05340	154.999	322.91	0.0031	18.148	40.135
JJC-02	9246	6.0981	4.845	0.08487	14310	0.11995	157.802	340.18	2.9137	21.823	33.726
JJC-03	1758	0.2027	0.314	0.05447	47	0.06793	133.854	283.87	0.0035	3.316	48.914
JJC-04	2243	0.2351	0.353	0.04411	33	0.05856	114.642	266.95	0.0041	4.651	43.524

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
JJC-05	2623	0.3619	2.491	0.35008	54	0.49835	116.724	275.82	0.0149	6.455	22.291
JJC-06	8952	0.3187	2.359	0.34139	70	0.50709	156.497	263.83	0.0120	20.164	17.807
JJC-07	2102	0.3348	2.890	0.38883	48	0.45103	109.128	269.15	0.0134	12.832	18.612
JJC-08	5299	0.3794	2.419	0.35955	81	0.58381	137.744	252.38	0.0156	14.179	18.696
JJC-09	6518	14.0348	19.601	0.45997	29285	121.53120	154.907	16319.96	2.3598	8.874	14.725
JJC-10	13627	12.7119	55.899	0.50571	29840	15.60600	189.930	12565.60	5.5855	34.026	15.437
JJG-01	24526	3.9645	17.900	0.12391	15274	3.87767	87.915	232.67	2.9505	43.847	19.097
JJG-02	31808	0.1741	0.386	0.04072	36	0.04949	103.295	197.85	0.0043	72.347	46.122
JJG-03	19978	3.5207	12.767	0.14479	15193	1.51699	98.624	180.98	1.9723	43.190	30.886
JJG-04	33843	9.5106	45.377	0.17243	35365	4.71019	107.383	131.62	8.0270	72.892	47.839
JJG-05	14324	7.2124	25.284	0.12033	30075	0.27600	90.922	233.52	3.0565	28.216	68.592
JJG-06	41385	8.3865	53.056	0.29927	44328	4.54264	132.624	263.58	7.4134	64.043	82.375
JJG-07	29566	8.0928	38.079	0.22674	42270	3.84057	142.426	180.17	4.1784	53.333	76.196
JJG-08	70593	8.5728	48.814	0.59401	58928	3.91057	207.489	146.86	15.8474	118.727	108.747
JJG-09	31927	7.2202	11.035	0.09705	40467	0.16359	143.197	173.91	3.0742	40.962	88.855
JJG-10	28399	8.1931	35.435	0.50814	39406	16.65383	118.204	241.17	4.7817	47.249	43.502
JJK-01	3685	1.5753	1.563	0.05508	9231	0.04987	70.293	180.60	0.1990	8.964	74.401
JJK-02	9728	3.3094	15.843	0.06036	18837	0.32648	69.267	191.34	1.6718	62.173	25.558

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
JJK-03	1541	0.2276	0.383	0.05303	30	0.04577	50.930	144.20	0.0053	5.093	6.201
JJK-04	9180	3.2220	21.099	0.14030	19488	0.22823	67.950	244.11	1.9481	74.254	57.605
JJK-05	4954	2.1792	10.648	0.11419	15938	0.13720	44.129	224.29	0.6567	15.755	91.888
JJK-06	4680	2.8266	8.905	0.08363	14772	0.07184	54.351	229.28	0.8224	11.835	89.123
JJK-07	4302	4.1537	4.475	0.11697	20532	0.19185	59.809	263.57	0.3690	5.968	266.065
JJK-08	14232	4.2920	30.599	0.11150	22809	0.20238	84.792	254.20	2.3877	105.191	61.789
JJK-09	2227	3.8478	6.223	0.09316	20382	0.04504	50.226	217.11	0.2755	12.340	141.149
JJK-10	8797	3.5129	14.861	0.09683	18827	0.17594	61.967	232.05	1.4878	76.901	86.732
Kot(MP-1)	2224	84.1500	1370.000	0.35120	42290	0.42180	325.200	120.30	6.1400	22.750	57.540
Kot(MP-2)	11890	89.5500	1828.000	0.45500	41910	0.06993	182.700	123.60	6.0130	38.130	64.480
Kot(MP-3)	9966	85.2400	1553.000	0.44140	42190	0.06743	210.200	95.51	5.2970	31.260	60.180
Kot(MP-4)	1445	81.1700	2616.000	0.41460	39760	0.06211	229.000	52.98	1.6720	23.410	96.780
KOT-01	10279	113.6252	4662.838	0.47283	71332	0.09096	1020.337	140.80	3.1707	262.556	30.659
KOT-02	53791	83.8528	1244.020	0.51041	37434	0.08981	591.108	161.80	6.9744	88.666	15.921
KOT-03	15370	80.6740	2125.400	0.49256	42682	0.09401	209.666	156.70	6.6963	23.692	15.845
KOT-04	62687	103.0556	2546.115	0.51432	43187	0.08980	885.357	169.11	3.5859	136.785	15.270
KOT-05	7121	87.4994	1451.672	0.57215	35729	0.08799	750.593	167.94	3.6289	70.172	9.443
KOT-06	4617	88.8200	1602.000	1.29700	35770	0.10330	115.000	100.50	2.4770	14.810	41.180

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
KOT-07	35610	94.4100	3627.000	2.56700	46870	0.05429	555.500	146.70	4.5740	107.000	44.250
KOT-08	7249	78.2100	1341.000	2.51900	42010	0.05985	374.000	191.80	6.2990	66.710	33.180
KOT-09	20820	83.8200	1367.000	1.72200	38630	0.07753	465.300	213.40	8.4060	56.930	34.080
KOT-10	20290	102.8000	3201.000	0.40780	46990	0.05813	376.000	176.70	4.2870	58.370	38.760
KOT-11	21940	104.1000	3291.000	0.39110	48490	0.06760	325.100	102.40	4.3720	50.080	37.920
KOT-12	19628	92.7521	2402.644	0.08404	47647	1.00427	375.772	127.32	14.3725	55.517	55.978
KOT-13	16008	85.8880	1802.188	0.07151	41634	0.87432	341.235	126.68	11.0025	43.475	51.601
KOT-14	2568	89.6967	3299.438	0.05287	45061	0.63052	413.515	144.35	1.9482	43.783	150.440
KOT-15	28960	106.6857	5386.251	0.06334	56553	0.83591	451.561	169.64	5.4215	98.399	77.618
KOT-16	25264	102.4266	3539.983	0.05471	48325	0.80864	368.535	132.62	5.4055	55.365	52.277
LBW1-01	10660	59.1900	1864.000	0.08683	23610	0.51730	142.100	758.00	8.3420	31.640	11.060
LBW1-02	7436	41.9100	1974.000	0.09187	16530	7.33300	61.960	443.90	8.8630	29.020	10.560
LBW1-03	3059	46.6100	777.600	0.05207	13680	0.02384	44.930	246.30	2.1900	13.980	4.723
LBW1-04	3034	43.8000	843.200	0.04536	12080	6.33700	28.000	369.30	2.3280	10.580	7.056
LBW1-05	2558	49.5900	463.900	0.08829	16230	0.04390	38.180	371.70	3.0710	6.412	10.930
LBW1-06	3617	51.4000	1042.000	0.10020	16170	0.05558	124.800	649.00	2.4650	13.030	11.660
LBW1-07	3749	6.4910	248.600	0.03634	1910	0.02159	65.070	158.80	1.1060	13.020	5.711
LBW1-08	3958	27.0700	1292.000	0.10280	9074	0.07589	72.030	626.50	4.9150	17.000	11.200

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
LBW1-09	3501	43.1300	1055.000	0.08619	13170	0.02603	24.790	400.80	3.0980	12.940	10.420
LBW1-10	3248	26.2500	708.600	0.09374	8610	0.05953	68.740	664.40	3.6380	11.050	10.470
LBW2-01	1232	31.4654	6.137	0.03603	10011	0.12838	22.476	447.95	0.3155	1.706	7.006
LBW2-02	11688	56.1296	3863.705	0.10088	17940	0.33392	55.316	1604.29	15.9825	55.378	15.986
LBW2-03	1372	36.3546	9.285	0.03629	9804	0.12717	20.708	618.21	0.2633	1.176	5.357
LBW2-04	1660	53.0697	111.371	0.04283	15897	0.16725	34.424	755.26	0.5807	2.231	8.672
LBW2-05	2100	87.9788	405.484	0.06212	22286	0.23746	39.510	1308.92	1.8500	4.668	12.607
LBW2-06	1906	46.2385	11.993	0.05484	12980	0.15548	18.246	919.94	0.5179	4.225	9.030
LBW2-07	3731	75.4578	1644.424	0.07240	19356	0.25201	44.295	1757.21	3.8246	16.088	13.461
LBW2-08	3471	77.0846	1020.591	0.07091	19851	0.26522	50.840	1574.25	3.0339	10.610	12.883
LBW2-09	2455	54.9975	1735.822	0.06796	16819	0.26710	38.334	1689.31	5.1673	11.811	13.381
LBW2-10	3616	81.0977	582.736	0.06905	22328	0.29036	52.205	1882.59	4.7158	13.003	14.700
LKPD-01	2051	0.3951	0.788	0.05787	1660	0.16213	95.797	174.46	0.0326	1.381	184.104
LKPD-02	1538	2.3073	0.875	0.05326	8403	0.13970	84.793	199.83	0.0774	1.958	422.641
LKPD-03	2109	3.1554	1.525	0.05194	7896	0.14352	25.502	338.90	0.2482	6.269	190.661
LKPD-04	1921	2.2941	1.296	0.06186	8433	0.14596	85.461	190.35	0.0845	2.609	402.980
LKPD-05	4285	1.5973	2.489	0.05774	6349	0.17328	31.139	336.65	0.4567	11.052	164.716
LKPD-06	2322	0.4071	1.309	0.05971	1677	0.14938	61.943	191.10	0.0344	2.407	186.883

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
LKPD-07	2034	0.3700	0.963	0.05757	3071	0.16660	23.069	438.97	0.3495	4.941	148.966
LKPD-08	35547	0.6907	1.348	0.05251	3874	0.28324	156.189	188.66	1.8086	7.207	131.423
LKPD-09	54080	0.5053	5.901	0.29823	4981	3.03927	216.854	179.41	1.3464	11.733	156.365
LKPD-10	47133	0.7030	1.100	0.13176	4669	7.01164	201.454	161.14	3.1181	8.916	94.654
LKPD-11	2200	0.2177	0.591	0.46942	2570	0.04167	103.658	165.17	0.0346	1.252	40.244
LKPD-12	74984	0.5204	0.880	0.48371	4534	1.28103	327.576	177.24	2.6154	12.668	26.948
LKPD-13	10140	0.2617	0.744	0.45007	3787	0.02580	89.243	402.87	0.3730	24.489	20.984
LKPD-14	8210	2.4173	0.557	0.45439	8814	0.03559	119.224	428.89	0.7501	17.360	18.662
LKPD-15	99602	0.4038	0.808	0.49246	3303	0.09141	446.060	223.34	1.4668	21.341	22.068
LKPD-16	3747	0.9298	7.391	0.35930	5010	0.14310	30.830	328.20	0.3951	11.820	148.700
LKPD-17	4805	1.1390	7.493	1.43400	5172	0.18370	29.390	321.70	0.4798	14.560	148.700
LKPD-18	2207	1.3220	7.598	0.94210	6460	0.25880	10.470	116.40	0.7434	5.121	146.700
LKPD-19	7085	1.4770	6.421	1.01400	6741	0.23080	33.940	312.20	0.7042	20.430	138.300
LKPD-20	2208	0.4501	1.753	0.94060	1471	0.04287	47.360	178.90	0.0372	1.850	130.400
PD-01	1708	2.0044	0.791	0.05249	1470	0.25221	1.576	192.06	0.0715	1.907	31.220
PD-02	1762	24.0847	1.267	0.06126	27885	0.32545	77.307	212.95	0.1500	2.364	190.765
PD-03	1687	0.8221	0.585	0.05150	770	0.35255	2.133	212.97	0.0471	1.205	15.468
PD-04	1719	2.5871	1.762	0.06186	4086	1.71931	5.960	177.04	0.0323	1.834	33.842

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
PD-05	1649	1.2068	0.707	0.05036	1121	0.26823	5.567	179.20	0.0190	1.339	49.572
PD-06	2011	1.5470	0.969	0.05174	1938	0.24440	4.627	243.83	0.0414	3.216	29.786
PD-07	1785	1.6196	0.873	0.05185	1427	1.10195	2.256	304.84	0.0305	2.678	9.692
PD-08	1755	1.0971	0.758	0.03522	678	0.05414	2.098	193.62	0.0371	1.676	9.562
PD-09	1687	2.2671	0.723	0.02724	1478	0.13537	2.251	333.59	0.0601	1.727	8.395
PD-10	1634	1.9469	1.070	0.02631	4469	0.09727	2.385	347.60	0.1025	1.891	8.301
PD-11	1901	13.3491	1.884	0.04549	9939	0.02515	6.556	213.79	0.0895	4.860	43.288
PD-12	1838	6.3418	1.454	0.05649	3572	0.03023	3.386	226.66	0.0253	1.474	16.003
PD-13	3385	2.1819	1.731	0.04645	1423	1.38453	7.321	229.33	0.0929	3.427	51.006
PD-14	1531	1.6763	1.514	0.05012	3215	0.02343	3.549	232.32	0.0517	1.565	60.547
PD-15	1669	0.8269	0.877	0.05848	711	0.08888	1.124	244.46	0.0555	1.626	36.693
PD-16	1636	0.6701	1.327	0.04560	599	0.01505	1.573	233.02	0.0305	2.092	33.997
PD-17	1864	6.6076	1.660	0.05783	3730	0.02943	3.135	253.33	0.0205	1.410	69.406
PD-18	1443	1.0907	1.700	0.04861	817	0.23827	1.360	210.08	0.0180	1.232	54.408
PD-19	1586	1.5080	1.059	0.04570	3323	0.04488	2.753	163.88	0.0444	1.556	63.227
PD-20	1675	1.4727	1.505	0.04203	2525	0.09150	2.430	178.06	0.0498	2.348	67.608
RDP-01	5271	4.3582	6.633	0.08545	9816	0.07692	38.649	190.92	0.5778	8.007	32.223
RDP-02	4017	5.3453	11.976	0.21093	9244	0.97501	139.822	174.22	0.9065	7.178	36.126

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
RDP-03	1827	2.1209	1.287	0.12915	8172	0.37762	49.829	136.72	0.4865	4.354	27.368
RDP-04	2222	3.7109	2.236	0.09766	9009	0.29137	31.201	175.50	0.3351	5.978	34.155
RDP-05	16128	3.6427	24.507	0.28277	9790	11.34843	28.445	210.79	2.4715	29.819	29.303
RDP-06	25674	5.1891	19.756	0.16445	13951	0.89244	96.172	144.96	3.6496	38.567	34.924
RDP-07	6060	7.0220	8.102	0.18126	12505	0.72266	199.698	282.53	1.4424	10.709	27.210
RDP-08	2194	3.1073	4.060	0.06276	7655	0.19639	21.792	155.31	0.4748	4.235	32.600
RDP-09	3993	3.6526	5.685	0.10229	9492	0.66600	29.303	141.79	0.8559	5.870	25.754
RDP-10	5393	2.6156	7.629	0.28016	8265	6.02314	30.581	170.28	0.7634	8.998	15.855
RDP-11	14130	1.0010	1.932	0.63740	2349	6.83500	93.570	409.00	4.7140	68.050	31.070
RDP-12	5914	1.0660	1.259	0.52660	2030	1.01600	47.380	494.90	1.7640	32.720	27.360
RDV-01	1276	2.4106	2.889	0.06526	5421	4.19301	17.907	171.61	0.0174	0.728	252.903
RDV-03	1429	1.8150	1.440	0.08685	9155	6.20208	29.915	211.25	0.0123	1.300	265.764
RDV-04	1185	4.7467	12.954	0.08755	7060	6.30798	161.048	191.87	0.0154	1.476	226.255
RDV-05	1702	2.0008	1.913	0.10625	4599	5.85611	17.732	288.60	0.0104	2.885	242.490
RDV-06	1713	1.9793	1.656	0.07648	4845	5.32474	16.932	264.39	0.0155	1.455	210.027
RDV-07	1770	2.1028	2.560	0.10252	4540	6.25825	14.528	255.05	0.0128	2.049	252.823
RDV-08	2051	2.6776	5.734	0.08093	7739	7.94283	18.702	269.81	0.0722	2.893	286.477
RDV-09	1439	3.0189	2.445	0.06672	7703	7.14964	31.822	204.40	0.0224	1.031	280.178

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India.   Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
RDV-10	2092	2.5326	6.563	0.11189	7603	12.04493	21.418	247.51	0.0537	3.022	268.293
RKA-01	36172	23.8300	50.719	0.16931	33503	1.50299	200.752	463.67	11.7137	87.370	48.140
RKA-02	91679	25.2074	156.835	0.45671	45416	8.79662	191.203	243.28	24.5474	178.612	61.182
RKA-03	34650	23.9842	73.438	0.20520	29006	1.30315	93.675	398.14	10.5958	72.636	43.974
RKA-04	50546	23.9374	114.613	0.30406	38445	6.18829	167.121	230.42	16.5218	100.020	53.707
RKA-05	31487	23.9020	70.710	0.41156	27138	11.61102	106.731	472.39	9.8072	71.977	12.736
RKA-06	41174	24.4836	83.459	0.11351	32260	2.05011	107.380	460.43	12.9429	81.430	13.144
RKA-07	56076	24.6131	144.295	0.26810	40377	8.75675	173.149	368.64	17.8488	110.471	15.011
RKA-08	58897	28.6735	103.171	0.23479	41109	4.81383	130.934	394.48	15.5174	98.947	14.308
RKA-09	8412	16.9576	61.345	0.91130	11031	28.87787	32.796	496.90	3.1146	28.916	11.431
RKA-10	50454	24.9277	101.510	0.25482	37012	7.75869	160.896	419.23	15.1434	110.402	14.195
RKA-11	53340	54.1900	29.970	0.49530	47750	0.55190	79.430	186.00	15.0100	123.200	51.650
RKA-12	184400	0.5864	35.260	2.41500	744	29.34000	7.861	7881.00	31.4400	144.000	46.860
RKA-13	41710	39.2100	2.555	1.88900	46280	1.67400	60.430	65.50	20.1300	66.250	40.540
RKA-14	34190	65.2700	125.100	2.62300	46150	10.88000	72.370	121.90	15.6300	96.070	38.120
RKA-15	79640	28.4400	4.366	0.57780	29210	1.20600	120.700	310.80	12.7100	123.800	72.200
RKA-16	70870	30.3100	5.881	1.42400	31840	27.91000	101.600	291.50	12.2500	104.300	76.120
RKA-17	72770	53.5400	67.710	0.49460	44240	3.49300	103.800	299.60	14.6400	181.800	84.910

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
RKA-18	67490	52.7800	62.470	1.63600	45120	1.07500	108.100	251.70	14.2100	161.700	38.920
RKA-19	172100	0.6079	31.540	0.54170	962	32.71000	8.845	7923.00	30.9100	117.300	64.660
RKA-20	220300	39.5200	4.618	0.69100	42080	0.35810	283.800	228.60	15.6800	343.100	50.730
RKG-01	6740	109.2000	2033.000	0.08467	50120	0.55850	220.000	132.90	6.8020	28.660	89.530
RKG-02	4630	93.5200	6092.000	0.08067	66190	0.52360	577.300	217.00	3.3830	42.260	182.200
RKG-03	1076	81.8600	20.620	0.05123	13750	0.32780	100.700	123.00	0.1620	0.911	104.100
RKG-04	3206	86.5000	509.500	0.06472	24670	0.37370	240.400	216.50	1.4970	5.731	195.600
RKG-05	4855	97.4400	5259.000	0.07609	47980	0.51450	693.300	188.40	3.1740	35.090	690.400
RKG-06	6467	88.6000	478.600	0.06296	13770	0.44380	102.900	189.70	3.0340	5.919	53.510
RKG-07	8234	80.4200	1072.000	0.06796	18100	0.49620	154.900	152.30	4.8370	5.722	41.720
RKG-08	2951	85.8300	51.220	0.05545	13900	0.43170	99.460	172.50	1.7900	3.492	34.300
RKG-09	2240	76.7900	180.300	0.04474	13700	0.38310	136.200	240.00	0.7921	1.311	71.970
RKG-10	2337	71.6400	186.600	0.04882	15490	0.40180	130.500	140.70	0.8817	2.454	75.010
RMP-01	95930	140.9543	3120.007	0.13284	61589	0.07326	299.700	176.44	25.1114	89.290	110.933
RMP-02	5609	93.8105	334.921	0.06213	25243	0.03468	96.600	172.02	2.6496	5.836	173.674
RMP-03	1159	84.4118	36.212	0.05137	12809	0.02912	30.090	167.39	0.1221	1.012	397.125
RMP-04	1306	92.9248	179.179	0.06767	32388	0.03678	42.370	164.56	0.2388	2.979	352.102
RMP-05	1548	70.7914	23.901	0.07887	18185	0.03158	69.470	147.12	0.4034	1.966	301.214

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
RMP-06	12800	86.0983	1575.066	0.06071	30355	0.04108	82.420	163.01	3.3739	16.090	161.729
RMP-07	6784	76.8377	1349.078	0.05603	32551	0.04453	82.930	157.85	5.1664	18.310	84.601
RMP-08	1556	99.1805	324.494	0.06336	24466	0.03499	45.520	158.41	0.4060	6.668	348.010
RMP-09	3636	93.0251	309.342	0.05786	24417	0.04311	416.754	158.90	2.8966	4.976	118.074
RMP-10	102417	137.4092	321.927	0.10759	60126	0.08274	497.692	169.43	19.6657	100.077	231.025
RRA-01	3308	3.1163	7.460	0.06180	2521	7.98333	6.077	137.63	0.1325	6.214	82.884
RRA-02	4687	3.3231	10.984	0.09033	2574	11.61522	41.167	156.31	0.7305	9.587	48.053
RRA-03	2382	2.0251	22.369	0.09453	2890	10.63241	7.645	205.73	0.7376	11.197	48.425
RRA-04	1349	2.2966	1.538	0.07258	1314	7.70511	2.720	129.56	0.0158	3.050	87.835
RRA-05	3513	51.6230	321.920	0.06383	24467	9.72520	40.133	139.62	0.9675	5.791	98.802
RRA-06	7531	61.6732	1556.495	0.05523	31276	13.81008	98.632	98.34	3.7643	16.610	42.225
RRA-07	2781	3.2286	4.685	0.07349	9525	5.25564	25.934	310.80	0.0952	2.642	306.807
RRA-08	7287	58.1925	851.218	0.06945	25694	13.65727	50.964	165.79	3.7636	13.189	38.802
RRA-09	2082	2.9701	8.525	0.07206	2246	4.15094	8.014	157.10	0.1576	5.243	72.619
RRA-10	1429	2.8026	1.376	0.05494	1651	4.33986	4.391	135.53	0.0244	3.043	93.597
RRD-01	1959	83.5705	468.532	0.05942	23530	0.21717	94.923	1472.26	0.8505	2.716	49.058
RRD-02	1348	70.2287	34.474	0.05255	18239	0.20317	166.615	1541.41	0.3647	1.351	36.550
RSA-01	1297	3.6641	1.631	0.05424	15934	5.11319	64.912	195.12	0.0136	1.301	246.869

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
RSA-02	1320	5.1421	1.383	0.06165	13638	6.36928	22.370	120.57	0.0118	2.380	89.875
RSA-03	1214	6.0493	1.430	0.09701	16179	0.04524	21.120	165.31	0.0098	1.577	80.478
RSA-04	1137	6.4652	2.669	0.05618	15802	0.06352	17.490	162.24	0.0180	1.814	68.272
RSA-05	1179	5.7960	1.100	0.06665	13160	0.03395	21.520	164.18	0.0107	1.635	94.933
RSA-06	1111	7.2579	2.135	0.06912	16361	0.07084	21.250	169.79	0.0137	1.779	97.477
RSA-07	619	3.6217	2.628	0.15386	12578	0.67927	390.200	137.55	0.0726	2.300	56.689
RSA-08	1313	5.1216	1.245	0.05699	14005	0.01753	22.740	179.86	0.0142	2.641	98.067
RSA-09	1396	4.4707	1.960	0.06763	18552	0.08618	37.540	238.48	0.0184	1.404	150.880
RSA-10	835	4.2234	2.743	0.13425	12130	0.50953	272.800	150.60	0.0553	1.994	94.474
RSA-11	4224	5.4810	0.832	0.47150	14760	0.16450	65.410	427.30	0.0548	12.790	81.720
RSA-12	1909	1.6460	2.129	0.88670	4381	0.02370	15.010	257.40	0.0252	1.895	201.000
RSA-13	6204	0.8008	0.476	0.44040	1967	0.02182	23.690	472.20	0.0515	10.510	66.550
RSA-14	2758	0.9182	0.841	0.46170	1610	0.02737	10.180	131.10	0.0404	5.050	29.670
RSB-01	3842	88.9800	1013.000	0.08024	31280	0.90570	313.300	146.30	2.7860	10.560	30.900
RSB-02	5575	92.4500	2055.000	0.09512	47530	0.09053	918.200	161.30	6.2750	25.710	12.160
RSB-03	5010	88.0500	978.000	0.06875	31170	0.14140	295.100	134.20	4.0220	13.750	10.930
RSB-04	16990	85.5100	2208.000	0.08434	37780	0.45300	520.800	136.30	9.3990	23.110	12.520
RSB-05	5190	91.7100	1698.000	0.06604	36250	0.02811	332.400	141.40	3.1360	22.690	27.190

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
RSB-06	5191	89.2200	1779.000	0.06471	34040	0.03105	331.700	138.40	3.0530	21.130	23.670
RSB-07	6175	98.2100	1697.000	0.09682	40680	0.03449	1172.000	160.90	6.4300	19.270	16.940
RSH-01	1810	93.0200	263.600	0.07499	22140	0.02323	253.600	186.30	1.5460	4.055	29.560
RSH-02	5376	76.6100	46.750	0.08140	14070	0.02304	117.800	161.40	5.1520	8.225	11.390
RSH-03	4720	76.1300	47.180	0.08208	13750	0.02431	101.900	163.20	5.0550	7.079	9.588
RSH-04	1755	96.9500	456.400	0.08034	28640	0.02116	268.000	177.60	1.3310	9.136	30.800
RSH-05	1730	97.1500	388.000	0.07673	28000	0.02098	248.700	181.70	1.5580	7.915	26.190
RST-02	996	70.2683	41.300	0.08989	17621	9.29932	46.893	107.45	0.1780	0.634	124.050
RST-03	10017	70.4040	1434.462	0.09214	27893	32.16222	98.268	101.36	5.1225	20.524	44.897
RST-04	1176	71.9147	15.751	0.06928	14639	20.54450	54.799	164.44	0.0815	0.974	143.533
RST-05	1139	73.5815	37.453	0.07457	12412	21.21967	22.748	119.42	0.2337	0.827	83.930
RST-06	1757	73.7518	170.759	0.06494	21493	22.92109	29.325	122.40	0.7184	2.157	64.934
RST-07	1135	74.3835	19.241	0.08463	13982	22.65678	68.949	137.40	0.0920	1.007	146.543
RST-08	6471	58.6065	863.937	0.09531	30108	30.80349	99.724	104.4	4.7977	12.239	42.486
RST-09	1127	72.6273	24.131	0.06839	12781	10.17662	48.925	162.17	0.0634	0.908	114.055
RST-10	7889	86.8858	1217.922	0.06623	18104	16.40526	19.418	96.35	6.2831	14.163	29.159
SB-01	13164	1.0651	4.558	0.09999	3967	0.22757	9.365	251.51	0.2577	9.379	38.473
SB-02	541	1.0158	0.966	0.22407	1995	0.06909	1.863	353.81	0.3421	1.143	25.852

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
SB-03	917	1.4161	1.289	0.19728	3602	0.11686	1.737	273.45	0.1769	2.456	32.784
SB-04	1970	1.1915	0.759	0.19231	2929	0.02745	7.110	255.39	0.1066	2.528	34.394
SB-05	1581	2.9249	3.338	0.23264	5573	1.17349	0.949	172.69	0.1836	3.965	31.463
SB-06	1773	0.9407	0.692	0.08388	2856	0.07853	6.754	247.38	0.1556	3.369	57.218
SB-07	21308	1.0883	15.135	0.15438	4606	0.33459	11.774	294.80	0.4185	13.660	53.352
SB-08	2245	1.9204	1.482	0.07875	2719	1.31363	7.922	208.90	0.1512	5.996	36.161
SB-09	9219	1.5950	4.050	0.09071	3672	2.27060	7.379	175.63	0.2255	6.973	48.052
SB-10	3043	1.7456	1.952	0.07052	2823	2.14967	13.311	160.48	0.1906	4.272	45.149
SC-01	1681	0.9669	2.308	0.25428	2338	0.44635	2.799	248.97	0.9594	4.004	26.098
SC-02	472	1.3294	2.696	0.62220	3118	58.19955	3.048	241.38	0.7902	1.801	23.082
SC-03	2205	0.9621	1.235	0.22107	2850	0.07625	15.716	242.39	0.1877	3.922	35.439
SC-04	2787	1.3421	5.309	0.30503	3925	2.41489	1.917	320.67	1.3106	3.708	23.514
SC-05	1880	2.0954	1.352	0.09015	6047	0.08207	45.448	277.36	0.1517	1.964	39.570
SC-06	13974	1.2766	8.474	0.16673	4250	5.01052	9.134	394.45	1.4010	18.719	53.125
SC-07	46462	1.5069	28.550	0.24325	7206	12.29991	17.947	256.16	2.0544	37.647	38.148
SC-08	1596	1.7055	0.912	0.24535	2715	0.03291	8.034	259.64	0.1601	1.802	13.489
SC-09	44776	1.5764	25.995	0.40530	6741	11.59144	19.667	251.75	1.9938	41.231	17.787
SC-10	1545	3.2160	2.164	0.08887	2255	2.57413	5.231	141.56	0.7177	5.415	18.987

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
SKK-02	2298	1.1315	1.423	0.18733	2650	1.87836	3.025	240.59	0.1163	1.695	42.527
SKK-03	4994	2.7071	4.523	0.08432	2609	2.29653	4.396	256.00	0.2136	9.593	41.467
SKK-04	3407	1.1562	3.553	0.08582	3202	2.32511	6.534	288.87	0.2235	7.184	39.147
SKK-05	1715	1.0525	2.131	0.19509	2982	0.11037	4.123	342.78	0.1924	3.108	43.932
SKK-06	604	1.0240	0.991	0.26006	2259	1.86413	1.152	3080.09	0.1092	0.550	80.241
SKK-07	6687	1.0210	1.258	0.47719	2377	1.50940	13.730	226.92	0.1036	2.902	5.687
SKK-08	1985	1.1378	1.154	1.24236	2393	1.67625	3.953	255.42	0.1203	2.434	34.678
SKK-09	1823	0.9898	1.180	0.07880	2377	2.76853	5.080	266.46	0.1091	1.519	47.380
SKK-10	2448	1.2815	2.502	0.09656	2232	2.87640	3.770	173.84	0.1213	1.369	80.801
SKK-11	18534	2.1003	9.144	0.08488	3985	6.92138	12.534	189.77	0.3506	12.595	42.354
UB(UC-1)	34008	12.9314	26.976	0.26189	10111	19.37513	29.739	146.28	4.0062	35.270	33.446
UB(UC-2)	1394	1.8742	1.573	0.06750	3162	0.11939	7.132	123.60	0.0514	1.459	68.800
UB(UC-3)	1376	9.9850	3.941	0.19560	5592	1.23314	349.471	106.04	0.4717	3.032	38.901
UB(UD-1)	8725	5.6373	10.667	0.17525	10188	6.13346	52.707	189.75	1.8476	11.659	24.819
UB(UD-2)	1169	3.1740	2.399	0.14179	6144	0.45597	11.710	106.78	0.0858	1.008	99.514
UB(UD-3)	1419	2.1278	2.960	0.10602	7217	0.35210	113.061	171.79	0.3511	3.834	293.667
UB(UK-1)	1029	8.1314	1.209	0.06563	5261	0.06132	2.729	115.67	0.0602	1.307	26.421
UB(UK-2)	84882	5.2631	67.294	1.07047	34855	59.23943	15.234	153.00	15.4225	88.665	56.410

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
UB(UK-3)	60518	7.1686	62.073	0.89535	30869	38.48763	7.242	98.43	11.8641	64.533	50.243
UB(UK-4)	11644	7.5949	11.549	0.29688	10588	5.96033	9.580	163.50	2.0860	13.203	26.881
UB(UK-5)	1330	3.7672	1.910	0.08689	4918	0.55289	4.541	106.41	0.3364	1.756	27.036
US-01	3821	1.9382	6.175	0.10456	2336	2.08466	45.715	397.75	0.5942	4.215	24.647
US-02	1393	2.5004	5.241	0.06818	2875	0.20543	3.054	173.34	1.0279	12.425	38.338
US-03	868	2.2831	1.720	0.05245	2562	0.08819	1.464	105.07	0.6915	7.536	17.800
USK-01	3757	8.9359	13.642	0.08328	18343	0.16158	17.218	113.58	0.3478	4.377	31.244
USK-02	1314	5.5032	1.051	0.09430	16638	0.11904	22.325	99.63	0.4377	1.169	18.786
USK-03	15176	22.2518	32.629	0.79592	25341	4.25442	22.979	100.08	0.9056	11.333	9.747
USK-04	973	5.1286	0.773	0.06945	15131	0.04643	26.782	95.16	0.0384	0.839	40.611
USK-05	1183	5.3961	0.963	0.07703	17360	0.06154	13.731	167.85	0.2293	1.089	24.590
USK-06	1018	5.2903	0.740	0.09120	16636	0.05224	15.798	159.51	0.0900	1.057	40.508
USK-07	6404	9.7520	9.242	0.16252	18830	0.31446	16.505	162.18	0.5947	5.902	21.675
USK-08	21622	21.5134	37.054	1.20747	26159	9.50274	28.792	210.42	0.9692	21.048	10.316
USK-09	1012	5.5750	2.587	0.07126	17944	0.04040	21.042	149.69	0.1553	2.200	31.180
USK-10	1043	7.3798	3.394	0.09823	16626	0.06327	13.575	174.20	0.1873	0.910	34.501
ZTAK-01	915	4.2290	8.264	0.06154	19580	0.04406	207.600	266.50	0.0717	1.595	24.060
ZTAK-02	990	2.9030	8.555	0.06317	12530	0.01483	296.800	134.90	0.0402	1.265	24.170

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)

Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
ZTAK-03	1229	2.8140	7.071	0.05227	19120	0.02090	159.400	266.10	0.0439	1.283	35.570
ZTAK-04	1281	34.8900	9.232	0.05443	33720	0.03144	107.700	155.20	0.8555	2.611	8.579
ZTAK-05	1700	33.4500	117.900	0.10630	21650	0.07776	237.800	196.20	1.5810	4.736	13.990
ZTAK-06	1349	16.0400	6.998	0.08312	23210	0.04347	226.500	210.10	0.4538	2.474	14.870
ZTAK-07	1231	22.9800	9.301	0.04559	16780	0.03208	23.450	263.40	0.2581	2.450	17.750
ZTAK-08	1207	12.6000	9.527	0.11830	18540	0.04724	194.400	196.50	0.2852	2.380	14.490
ZTAK-09	1373	11.3200	14.820	0.15110	19290	0.06931	204.000	214.40	0.5196	2.801	18.730
ZTAK-10	1063	7.9570	7.066	0.04318	16840	0.02711	24.980	313.80	0.0886	2.142	17.400
ZTT-01	1892	52.4500	4920.000	0.06615	54550	0.49550	669.800	148.60	2.8190	47.000	54.050
ZTT-02	1523	41.7200	2236.000	0.05878	65420	0.47570	172.300	126.90	3.1290	22.820	34.810
ZTT-03	1592	37.3800	3326.000	0.05382	39190	0.41930	235.000	137.40	1.4500	24.530	61.870
ZTT-04	1514	50.3400	2518.000	0.06244	63500	0.53150	160.500	62.10	3.5430	20.450	39.840
ZTT-05	1633	170.1000	4098.000	0.09201	53870	0.81380	423.600	121.10	5.2330	36.270	56.920
ZTT-06	1080	53.7000	222.500	0.03786	30280	0.39580	273.900	165.90	0.6289	5.898	36.200
ZTT-07	1612	0.5841	2.241	0.17215	2334	0.13854	3.700	98.70	0.0936	1.761	108.510
ZTT-08	1204	54.4200	1084.000	0.08185	81060	0.57460	138.500	102.90	3.7250	11.110	91.310
ZTT-09	1972	45.8100	3716.000	0.06229	47770	0.45240	48.010	56.40	2.6810	32.990	83.480
ZTT-10	1070	36.5000	86.140	0.04869	40970	0.37860	26.240	102.90	0.2334	1.674	111.800

Appendix 7.3 (cont.): INAA data for steatite samples collected from deposits in Pakistan and India. Data in parts per million (PPM)											
Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
ZUN-01	1120	12.4797	15.578	0.03722	4410	0.08514	4.230	442.06	0.1168	3.214	20.790
ZUN-02	1086	15.2697	1.404	0.05056	7417	0.07985	4.679	534.62	0.0837	2.040	24.860
ZUN-03	1089	19.2626	16.370	0.05061	7964	0.09622	42.143	452.00	0.4978	5.370	18.331
ZUN-04	1489	52.1921	13.663	0.06762	19529	0.15153	88.132	748.29	0.9862	3.471	30.739
ZUN-05	2840	103.5938	2778.927	0.08621	46592	0.28995	122.946	1311.32	4.9705	45.031	65.753
ZUN-06	2138	71.1968	1539.828	0.06887	37333	0.24959	106.126	1179.33	4.5573	20.270	30.152
ZUN-07	1323	24.0303	32.658	0.03064	17219	0.12811	19.320	668.50	0.5629	14.672	27.439
ZUN-08	1360	40.0954	445.997	0.06363	18490	0.13738	30.910	839.51	0.5906	11.126	38.723
ZUN-09	1218	19.1010	16.659	0.04888	13395	0.29179	5.224	11933.54	0.2376	11.167	23.207
ZUN-10	1339	28.2447	88.080	0.05245	14907	0.29558	11.433	13367.44	0.3530	10.075	24.894

Appendix 7.4: INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)

Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H87/33-02	2048	0.6936	2.012	0.06920	3658	0.16965	4.075	569.98	0.0531	3.622	93.790
H87/86-228	1803	1.7530	6.358	0.06166	3928	0.16071	9.868	417.28	0.0964	4.270	112.141
H87/86-229	2087	1.2263	2.577	0.05540	4689	0.17738	12.586	477.79	0.0671	3.887	102.267
H87/86-236	2085	0.8963	2.800	0.06142	4477	0.15191	12.228	504.37	0.1688	4.562	138.319
H87/237-86	2160	0.7003	2.667	0.05617	5019	0.15229	4.626	675.22	0.0594	4.045	97.469
H88/340-24	1565	8.7269	8.260	0.05768	2302	0.12548	6.918	355.27	0.0425	3.376	75.202
H89/1018-13	1491	0.5875	1.092	0.05933	2154	0.17290	2.772	304.81	0.0332	0.834	76.968
H89/1121-5	9444	0.8239	6.740	0.43926	2878	15.36836	4.039	693.28	1.4736	4.571	62.038
H2000/2230-14	1566	0.5745	2.339	0.32220	2530	0.03220	5.329	477.10	0.0407	2.171	113.200
H2000/2230-15	1796	0.3977	6.596	0.27770	2578	0.11300	6.788	404.10	0.0735	3.864	175.600
H2000/2230-16	1540	0.2525	0.992	0.48474	2116	0.08471	12.330	424.51	0.0350	2.193	10.747
H2000/2230-17	964	0.5984	4.444	0.49046	3228	0.09129	3.698	474.61	0.0457	1.197	15.049
H2000/2301-176	1614	0.3186	1.176	0.50474	2440	0.11467	5.805	365.22	0.0548	2.501	10.691
H2000/2301-177	1675	0.4263	1.812	0.46841	2968	0.11826	4.349	435.86	0.0685	3.264	13.189
H2001/2373-10	1527	0.9361	0.890	0.12273	4391	0.02220	9.209	600.57	0.0312	0.864	166.649
H2000/2753-17	1704	0.6088	0.713	0.06119	1639	0.03378	12.172	516.82	0.0356	0.831	33.620
H2000/2774-14	25996	2.4339	16.812	0.27295	7037	33.85512	17.498	961.72	1.6237	36.504	15.681
H2000/2774-15	1777	0.6635	0.630	0.09948	1640	0.05545	3.349	604.26	0.0877	0.721	16.766

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H2000/2789-30	1915	0.6296	1.015	0.12053	3000	0.07677	5.179	668.02	0.0303	0.730	31.703
H2000/2880-16	2178	0.7311	1.602	0.06210	2924	0.08398	22.701	744.61	0.0269	1.188	28.404
H2001/2913-12	1920	0.8082	0.754	0.31509	3359	0.14078	7.871	801.75	0.0484	1.113	74.926
H2001/2920-7	1111	0.6078	0.886	0.12777	3045	0.03029	3.725	361.35	0.0387	0.737	120.657
H2001/2922-6	1414	0.5917	0.556	0.05952	2376	0.05637	5.415	293.21	0.0390	0.934	98.276
H2001/2939-25	1550	0.9066	1.644	0.07531	8401	0.31191	179.866	384.30	0.1217	1.916	95.450
H90/3030-55	1551	0.6282	0.746	0.08979	5127	0.03268	6.408	408.17	0.0226	0.924	130.403
H90/3068-50	1596	0.8657	1.411	0.06070	3877	0.03733	5.183	585.77	0.0246	1.455	88.372
H90/3290-17	1561	0.6749	1.405	0.16116	1778	0.04251	2.082	737.58	0.0654	1.904	85.343
H93/3534-13	2001	1.0981	3.055	0.14927	4282	0.19795	14.556	971.62	0.0652	2.520	147.739
H93/3710-16	1516	0.4904	1.976	0.07162	2517	0.06260	6.046	552.65	0.0594	1.645	59.855
H93/3710-70	1747	0.6235	3.740	0.07846	2673	0.08883	9.024	719.89	0.1316	4.178	216.293
H93/3808-52	1535	0.5978	0.705	0.11724	1757	0.03949	2.866	584.69	0.0595	0.938	83.005
H93/3869-24	1545	0.9480	0.713	0.05340	2080	0.07567	6.785	431.07	0.0501	0.903	73.704
H95/4453-22	1468	0.6378	0.936	0.07793	2988	0.02537	5.263	532.65	0.0300	0.920	128.348
H95/4613-42	1626	0.4385	0.498	1.14059	1480	0.04576	6.963	669.88	0.0721	1.332	35.312
H95/4615-94	1897	1.0672	1.057	0.08311	3835	0.20093	8.262	660.78	0.1029	1.215	63.778
H95/4723-2	1328	0.5706	2.034	0.05157	2667	0.16767	27.227	707.18	0.1308	1.543	64.732

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H95/4726-101	1910	0.4867	1.063	0.04422	1694	0.06002	4.057	708.36	0.0364	1.595	84.159
H95/4746-7	1516	0.6595	0.687	0.05577	2212	0.02830	1.820	541.39	0.0358	1.167	103.450
H95/4751-8	1885	0.5744	0.819	0.11345	2635	0.13825	20.026	1041.44	0.0939	1.643	32.813
H95/4919-62	1185	0.7353	1.672	0.07132	2359	0.49272	51.771	564.43	0.2421	1.981	13.615
H95/4950-4	1673	0.6600	0.537	0.12262	2845	0.02256	4.600	609.57	0.0379	1.105	36.725
H95/4954-18	1322	0.4472	0.974	0.09818	1938	0.02474	3.828	647.40	0.0331	0.813	22.447
H95/4961-176	1433	0.6354	0.779	0.11414	3345	0.04042	3.845	682.24	0.0503	1.064	23.343
H94/5135-34	1990	0.3910	7.257	0.14091	1226	0.09800	2.279	507.23	0.1290	1.821	72.690
H95/5184-1	1254	0.5649	0.969	0.08989	2155	0.02363	3.770	327.90	0.0320	0.840	103.985
H95/5713-145	1810	0.7737	1.266	0.06631	2268	0.03384	7.164	697.78	0.1004	1.636	89.964
H95/5734-31	1590	1.2582	1.000	0.07435	2617	0.03433	4.885	608.96	0.0404	1.268	100.125
H95/5747-125	1529	0.5098	1.075	0.06686	2639	0.03519	4.464	489.91	0.0291	1.161	63.928
H95/5749-97	1363	0.7542	0.635	0.08768	3423	0.03623	4.201	643.82	0.0161	1.046	122.396
H95/5759-25	1636	0.7120	0.851	0.04045	2842	0.03462	3.704	567.39	0.0323	1.587	77.658
H95/5763-19	1571	0.8232	0.758	0.07527	2626	0.04487	10.005	750.27	0.0431	1.799	141.979
H95/5802-5	2091	0.8686	0.809	0.40750	3753	0.08015	66.755	620.20	0.0589	0.985	82.870
H95/5803-25	1655	0.7372	1.692	0.14813	6033	0.11117	174.265	703.34	0.0581	0.897	288.355

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H95/5820-11a	1261	0.6224	1.077	0.08811	1363	0.03201	1.892	477.13	0.0148	0.860	105.058
H96/5837-18	1326	0.3213	0.528	0.12375	1978	0.02819	4.856	539.61	0.0388	0.962	191.366
H96/6218-8	1592	1.1237	0.673	0.12800	3572	0.09552	2.989	1138.76	0.0787	1.109	24.592
H96/6219-44	1309	0.4862	0.668	0.06733	1922	0.03336	11.306	458.98	0.0391	0.965	37.301
H96/6234-2	1303	0.4887	0.607	0.07568	2316	0.02720	4.065	392.41	0.0314	0.773	97.483
H96/6257-21	1430	1.0858	0.545	0.14628	4108	0.02347	3.656	467.05	0.0325	0.836	168.416
H95/6509-97	1958	0.4702	1.517	0.07118	4777	0.10161	22.064	722.29	0.0230	1.582	41.605
H96/7105-8	1835	0.5276	0.645	1.15691	2313	0.05698	4.923	593.76	0.0537	1.082	42.632
H96/7106-27	1574	0.3944	0.804	0.07924	2250	0.39446	88.955	593.87	0.1138	1.932	97.271
H96/7118-9	1717	0.7717	1.605	0.13950	2492	0.37042	61.076	661.47	0.0771	1.860	141.859
H96/7153-14	2054	0.8125	1.224	0.07762	4670	0.07410	6.651	906.99	0.1039	1.653	126.130
H96/7156-14	1714	0.3722	1.675	0.09426	2597	0.05294	5.610	447.65	0.1029	1.390	68.086
H96/7239-26	1780	0.6479	1.934	0.07958	2038	0.09767	4.859	529.28	0.1028	1.587	17.117
H96/7256-43	1537	0.6898	0.913	0.13925	3190	0.12141	8.093	505.38	0.0545	0.802	23.826
H96/7257-46	4060	0.7658	2.596	0.04421	2098	0.03628	2.383	782.50	0.0265	1.310	27.685
H96/7333-22	4291	0.8249	1.927	0.12301	2395	0.58948	9.824	683.50	1.0023	2.159	38.809
H96/7358-11	2105	0.9389	1.213	0.12895	3465	0.23081	19.331	880.46	0.0807	1.881	141.163

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H96/7401-63	17284	1.2007	23.644	0.28853	4619	10.60924	22.630	682.77	2.2431	14.211	18.200
H96/7410-1	543	0.4993	1.524	1.19500	2470	0.07171	1.064	154.50	0.0619	0.567	15.330
H96/7410-2	1598	0.5093	1.614	0.22257	2531	0.06751	2.844	429.15	0.0437	0.911	88.935
H96/7414-46	8029	0.7899	5.574	0.21674	2249	2.19513	6.818	656.71	0.8936	6.146	54.917
H96/7414-47	1857	0.5334	1.637	0.59470	4501	0.23800	33.720	652.30	0.0789	1.201	16.790
H96/7467-658	88516	2.329	113.877	2.477	12741	63.574	45.889	2722.55	8.224	64.292	43.999
H96/7467-790	1667	0.7843	0.836	0.13350	2202	0.08082	17.419	766.14	0.0303	1.355	28.503
H96/7531-16	2071	0.8768	5.165	0.09811	4541	0.11687	4.681	1270.88	0.0891	1.759	41.952
H97/7619-3	1655	0.3622	3.502	0.10151	2614	0.18101	6.656	438.45	0.1030	2.435	102.207
H99/7636-8	2124	1.2381	1.807	0.06132	6026	0.24069	58.721	534.99	0.0779	16.563	98.514
H99/7637-32	1853	1.4450	1.633	0.04334	4703	0.16588	35.718	415.95	0.0976	3.219	122.390
H99/7638-1	1869	0.4164	2.611	0.10212	4935	0.11426	4.396	479.11	0.0910	12.891	71.325
H99/7649-42	1970	0.7385	1.528	0.12647	2681	0.04569	5.374	529.31	0.0688	2.122	154.091
H97/7780-10	1603	0.5884	0.719	0.10167	2123	0.09512	4.090	687.75	0.4052	1.764	63.166
H97/7780-8	3186	0.8741	2.777	0.07543	2160	0.22341	7.285	486.41	0.5741	1.684	74.104
H97/7780-9	1566	0.4290	2.361	0.04539	1860	0.21949	4.498	795.76	0.0511	1.472	125.591
H97/7784-156	2053	0.8499	0.836	0.52710	2849	5.32711	5.474	473.19	0.3680	1.012	9.679
H97/7784-157	5922	0.6855	1.363	0.38200	5327	0.02745	27.820	1240.00	0.0529	3.268	85.380

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H97/7784-158	8606	0.7940	0.704	0.62220	4137	0.03545	16.420	2096	0.7103	5.714	68.530
H97/7784-159	18390	0.9886	3.241	0.57970	2606	1.87000	8.889	3009	1.3170	11.820	49.260
H97/7784-16	1983	0.6449	0.702	0.42850	3939	0.02739	4.329	494	0.0119	0.897	147.300
H97/7784-17	1757	0.4613	1.467	0.50166	2628	0.06017	3.020	527.33	0.0518	0.861	10.816
H97/7784-18	1664	1.0544	4.001	0.54321	2415	0.07093	5.113	514.83	0.0363	0.648	10.209
H97/7784-19	9294	1.4114	6.768	0.53097	4495	3.51956	4.131	663.97	1.6514	4.731	6.293
H97/7784-20	1881	1.2938	3.631	0.50932	2057	0.03803	3.115	421.69	0.0495	0.864	9.737
H97/7784-21	1612	52.0800	3192.0	0.10460	55550	0.54030	32.350	15090	3.5670	18.150	64.040
H97/7784-22	1884	0.2482	1.374	0.49488	2878	0.06257	3.104	511.50	0.0965	1.445	6.524
H97/7784-23	1863	0.5209	1.233	0.32800	2688	0.07389	3.323	400	0.1574	1.032	130.300
H97/7784-24	19440	1.6760	15.710	0.32250	5417	9.88200	11.630	646.30	2.1070	3.188	78.860
H97/7784-25	1560	0.4580	0.829	0.46907	2315	0.05173	3.012	455.18	0.0401	0.813	10.109
H97/7784-27	2104	13.2252	81.349	0.49928	1861	0.28395	4.990	496.58	0.6556	2.831	6.574
H97/7784-28	2054	0.4780	1.415	0.50380	2696	0.05971	4.460	591.89	0.0961	2.201	9.067
H97/7784-29	1910	0.4477	1.656	0.47837	2512	0.12922	18.280	544.17	0.1083	1.690	9.351
H97/7784-30	513	0.4103	1.390	0.13002	2989	0.03090	1.103	450.69	0.0513	0.442	88.492
H97/7784-31	617	0.4982	5.937	0.34690	2330	1.13100	9.594	142.60	0.1273	0.832	119.400

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H99/7794-3	4600	0.2839	2.942	0.08072	3717	0.17823	4.555	340.42	0.1448	6.035	142.601
H98/8342-3	7107	1.0350	8.298	0.17775	3715	7.42393	5.943	797.95	1.4574	5.820	11.459
H98/8355-2	1888	0.5139	1.232	0.10985	2867	0.05477	1.446	709.22	0.0816	1.462	64.640
H98/8364-5	2051	0.4365	1.221	0.05151	2313	0.11733	4.458	557.29	0.1947	1.906	55.086
H98/8407-39	1778	0.9304	4.195	1.26500	1728	0.25080	53.410	442.10	0.0579	1.640	13.680
H98/8407-40	1269	1.1110	3.121	1.31000	2116	1.98800	1.648	106.90	1.3160	1.024	7.676
H98/8410-12	9141	1.1994	9.302	0.23644	2627	6.47423	8.383	691.46	1.1734	5.834	43.818
H98/8486-50	1718	1.2870	5.323	0.33460	3235	2.55600	1.362	174.60	0.6837	1.516	105.600
H98/8487-32	1907	0.4496	0.698	0.84800	2740	0.05490	3.669	483.30	0.0284	0.762	9.459
H98/8487-33	760	1.7753	9.249	0.16709	1329	0.06247	1.402	424.39	0.0222	0.575	102.432
H99/8490-103	241	0.5523	2.182	0.10700	1602	0.28657	3.488	668.31	0.0984	0.440	95.468
H99/8492-229	1068	0.5015	1.139	1.11400	810	0.35480	5.865	340.50	0.0698	1.193	13.770
H99/8497-3	1465	0.5716	1.987	0.15151	2199	0.40107	26.210	490.13	0.1389	1.539	76.924
H98/8668-2	1825	24.9866	671.418	0.88296	33729	0.14137	59.035	443.16	1.3826	9.412	317.395
H99/8760-77	2185	0.6666	4.872	0.06074	7353	0.08911	7.656	1099.17	0.0375	17.620	85.628
H99/8956-1	582	0.6865	1.050	1.33900	4824	0.06759	2.152	222.80	0.0584	0.583	22.830
H2000/8983-44	1686	0.4280	0.994	0.51920	2389	0.32610	26.450	668.40	0.1156	2.401	14.820

Appendix 7.4 (cont.): INAA data for steatite artifacts from Harappa. Elemental data in parts per million (PPM)											
Artifact (year/lot-rec)	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
H2000/8992-1	2129	0.2670	1.082	1.03400	5480	0.08161	8.968	524.10	0.0369	1.329	11.480
H2000/8997-4	1993	0.3954	0.652	1.05500	2793	0.04022	4.007	476.30	0.0360	0.913	12.340
H2000/9442-2	6493	1.4664	6.495	0.19253	2491	4.01521	12.580	347.38	0.7164	3.745	67.164
H2000/9443-6	13130	1.0476	6.338	0.31612	3968	12.67332	5.966	598.01	1.2442	6.264	47.379
H2000/9443-7	1136	0.3300	2.319	1.02100	9097	0.05017	3.527	255.60	0.0424	0.946	10.140
H2000/9445-1	54600	0.4794	1.643	1.63600	3285	0.06579	600.0	10000	0.0750	90.00	11.190
H2000/9445-2	392	0.5189	1.437	0.21518	3615	0.15337	13.210	519.23	0.1468	0.424	91.974
H2000/9447-5	7535	1.4020	14.370	1.15700	4953	18.94000	4.595	293.00	1.9410	3.008	11.030
H2000/9514-93	1964	0.4098	1.126	0.07465	2718	0.05535	4.490	468.36	0.0535	1.092	18.043
H99/9737-22	1331	1.0386	0.682	0.12720	2807	0.02977	1.344	367.15	0.0248	0.969	149.973
H99/9747-33	1715	0.6065	0.709	0.11860	2869	0.10796	5.540	738.14	0.0553	1.347	127.436
H99/9756-16	1487	0.5775	1.039	0.06759	2551	0.02069	4.480	486.93	0.0380	1.370	149.495
H99/9779-4	1496	0.5006	1.104	0.10644	3218	0.03175	4.131	446.97	0.0705	2.233	163.126
H2000/9840-8	22771	1.7333	19.051	0.12146	7585	0.38133	11.975	785.50	1.2201	15.289	141.286
H2000/9973-13	657	0.2368	0.750	0.93340	3267	0.10660	19.390	150.70	0.0175	0.767	18.900
H2000/11001-6	1990	0.4956	1.1940	0.1920	5136	0.0648	6.8318	502.81	0.0555	5.661	27.620
H2001/11562-26	2158	0.5767	2.124	0.12408	2657	0.07452	6.150	790.88	0.0694	3.373	18.882
H2001/11923-9	1834	0.6998	1.133	0.09334	2047	0.03676	4.341	599.76	0.0990	1.063	23.414

Appendix 7.5: INAA data for unfired steatite artifacts from Mohenjo-daro (MD).
Elemental data in parts per million (PPM)

Sample / Area	*Parent-rock 1st & 2nd PGM*	Al	Co	Cr	Eu	Fe	La	Mn	Na	Sc	V	Zn
MD-S1 / DK-A	SB / SKK	1744	0.2975	1.628	0.08737	2181	0.11994	4.882	709.45	0.0628	1.591	30.013
MD-S2 / DK-A	PD / SKK	2106	0.8963	1.627	0.07933	2438	0.08497	5.947	936.66	0.0394	1.353	45.075
MD-S3 / DK-A	SKK / SB	2140	0.6876	3.459	0.08595	3229	0.19026	9.672	775.72	0.0795	1.278	26.517
MD-S4 / DK-A	ATM / SB	1481	0.8113	3.792	0.06290	3316	0.10597	4.724	852.45	0.0756	2.505	31.386
MD-S5 / DK-A	ATM / SKK	1441	0.8831	1.853	0.09926	5241	0.23115	6.751	1214.59	0.0697	1.470	34.255
MD-S6 / DK-A	ATM / ANB	1553	0.9122	1.345	0.08971	1956	0.13561	5.746	1686.97	0.0544	2.723	21.419
MD-S7 / Moneer	SB / SKK	820	0.8168	1.331	0.07102	5367	0.04619	2.880	679.55	0.0990	1.471	30.777
MD-S8 / Moneer	ATM / SB	1858	1.0956	1.348	0.04398	4215	0.08384	7.104	1318.33	0.0720	2.539	30.532
MD-S9 / Moneer	ANB / ATM	3361	1.6533	2.889	0.08035	4775	1.30215	23.849	7552.83	0.3890	5.474	35.939
MD-S10 / Moneer	PD / GMP	1828	4.4400	1.837	0.07191	3923	0.30075	16.615	300.98	0.1155	3.508	18.608
MD-S11 / Moneer	SB / SC	1671	0.6067	1.920	0.06065	2389	0.14230	9.755	326.63	0.0801	1.646	25.208
MD-S12 / DK-A	SC / SB	1938	0.4789	1.838	0.07169	2302	0.36967	13.907	526.06	0.1618	3.004	19.741
MD-S13 / DK-A	RDP / ATM	1613	0.6379	1.550	0.06836	2793	0.42014	151.612	1090.83	0.2931	1.703	12.789
MD-S14 / DK-A	PD / SKK	4063	1.2040	3.688	0.06431	2483	0.10103	8.315	531.95	0.0384	1.623	46.903
MD-S15 / DK-A	SB / SKK	1539	0.4198	3.213	0.05401	2984	0.32981	8.809	381.28	0.0875	1.799	30.494

Appendix 7.6: INAA data for unfired steatite artifacts from Mehrgarh (MR) and Nausharo (NS)
Elemental data in parts per million (PPM)

Sample ***[artifact context / number]***	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
MR-s1 [MR4 Atelier]	2143	0.2647	15.234	0.10067	609	0.1043	8.222	979.05	0.1783	20.02	6.816
MR-s2 [MR4 Atelier]	1847	0.2706	12.179	0.10085	439	0.0990	5.676	860.26	0.1486	15.21	6.593
MR-s3 [MR4 Atelier]	2629	0.2604	26.586	0.08776	961	0.1291	5.179	1198.54	0.2850	23.35	8.364
MR-s4 [MR4 Atelier]	1945	0.2434	37.275	0.0755	523	0.3790	4.763	1350.85	0.1789	66.95	4.277
MR-s5 [MR4 Atelier]	1403	0.1697	18.895	0.0732	356	0.4688	6.261	1037.41	0.1335	68.82	5.582
MR-s6 [MR4 Atelier]	1786	0.1874	20.7595	0.0855	584	0.1371	5.681	1409.39	0.2706	105.7	7.646
MR-s7 [MR4 Atelier]	1987	0.4336	40.389	0.0946	1135	0.2655	8.8041	1476.75	0.2175	84.12	7.618
MR-s8 [MR.99.03.145.12]	2553	0.4108	15.326	0.0956	477	0.4933	14.28	1183.66	0.1702	26.26	7.327
MR-s9 [MR.00.3S.508.08]	3468	174.66	7407.3	0.0966	66212	0.1160	294.9	208.78	2.1511	30.70	37.097
MR-s10 [MR.00.03.390]	3430	0.4513	41.0334	0.4934	1078	0.1338	5.548	1198.18	0.3797	83.05	11.278
MR-s11 [MR.00.03.109.115]	62049	71.218	387.088	0.0519	112956	15.754	1876.2	190.48	104.7	574.5	12.001
MR-s12 [MR.98.03.87.02]	3184	0.8116	42.3403	0.0945	1970	0.0865	13.181	2201.85	0.3861	72.10	6.662
MR-s13 [MR.00.03.183.219]	1386	41.617	1472.49	0.0835	34553	0.0845	38.83	308.17	1.2495	7.882	17.410
NS-s1 [NS.90.09.21.02]	1408	118.14	1826.7	0.06186	12059	0.1655	135.03	428.62	1.203	9.199	14.256

Appendix 7.7: INAA data for unfired steatite artifacts from Gola Dhoro (GD), Nagwada (NGW), unknown Loralai site (LOR) and Tepe Hissar (TH). Elemental data in parts per million (PPM)

Sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Mn**	**Na**	**Sc**	**V**	**Zn**
GD-s1	11371	85.764	2546.5	0.32230	35012	0.07018	132.05	1892.7	2.2341	23.132	62.057
NGW-s1	8243	57.7813	894.30	0.07159	23523	0.03659	313.105	133.47	4.3543	25.202	10.412
LOR-s1	191700	0.3520	7.579	3.35800	3070	36.5800	6.941	250.40	3.6100	8.385	30.250
LOR-s2	2174	48.2109	4262.9	0.0925	43246	0.5044	106.2584	427.34	2.9106	33.7013	16.785
TH-s1	1336	6.1175	1.2358	0.1375	28101	0.3156	88.1441	951.29	0.0571	4.819	128.74
TH-s2	36727	1.1252	84.56	0.1183	13020	4.8644	32.5707	745.67	4.0722	102.23	10.286
TH-s3	1219	3.4656	1.7806	0.1380	14026	1.0090	163.3491	332.54	0.1010	1.5844	101.64
TH-s4	1221	2.8522	0.9222	0.0932	7627	0.0502	27.5931	1122.9	0.0657	1.9529	22.322

Appendix 7.8: Standardized canonical discriminant function coefficients for scatterplots in Chapter 7 generated using canonical discriminant analysis.

Figures 7.13 & 7.14	*Function 1*	*Function 2*
Log Al	.062	-.504
Log Co	1.303	.937
Log Cr	.605	-1.100
Log Eu	-.089	-.043
Log Fe	-1.363	-.884
Log La	-.442	.318
Log Mn	.278	-.239
Log Na	.237	.452
Log Sc	.513	.573
Log V	-.449	.940
Log Zn	.072	.198

Figure 7.16 A	*Function 1*	*Function 2*
Log Al	.791	.059
Log Co	-.091	-.547
Log Cr	.423	.097
Log Eu	.442	.350
Log Fe	.256	.372
Log La	.200	1.120
Log Mn	.363	-.147
Log Na	-.753	-.054
Log Sc	-.418	-.551
Log V	-.657	-.224
Log Zn	.261	-.321

Figure 7.16 B	*Function 1*	*Function 2*
Log Al	-.333	-.670
Log Co	1.599	-.657
Log Cr	-.369	.226
Log Eu	-.069	-.042
Log Fe	-1.829	.676
Log La	-.120	-.213
Log Mn	.199	.671
Log Na	.382	.612
Log Sc	1.005	-.670
Log V	.373	.896
Log Zn	.261	-.081

Figure 7.18	*Function 1*	*Function 2*
Log Al	-.515	-.295
Log Co	.670	-1.114
Log Cr	.323	.353
Log Eu	-.313	-.071
Log Fe	-.826	1.306
Log La	-.134	-.037
Log Mn	.307	.269
Log Na	.724	.479
Log Sc	.661	-.455
Log V	.206	.119
Log Zn	-.071	-.347

Appendix 7.8 (cont.): Standardized canonical discriminant function coefficients for scatterplots in Chapter 7 generated using canonical discriminant analysis.

Figure 7.19 A & B	*Function 1*	*Function 2*
Log Al	-.803	-.248
Log Co	.317	1.304
Log Cr	.226	-.129
Log Eu	-.106	-.299
Log Fe	-.545	-.550
Log La	-.019	.099
Log Mn	.800	-.489
Log Na	.157	.597
Log Sc	-.122	-.087
Log V	1.011	.290
Log Zn	.302	-.333

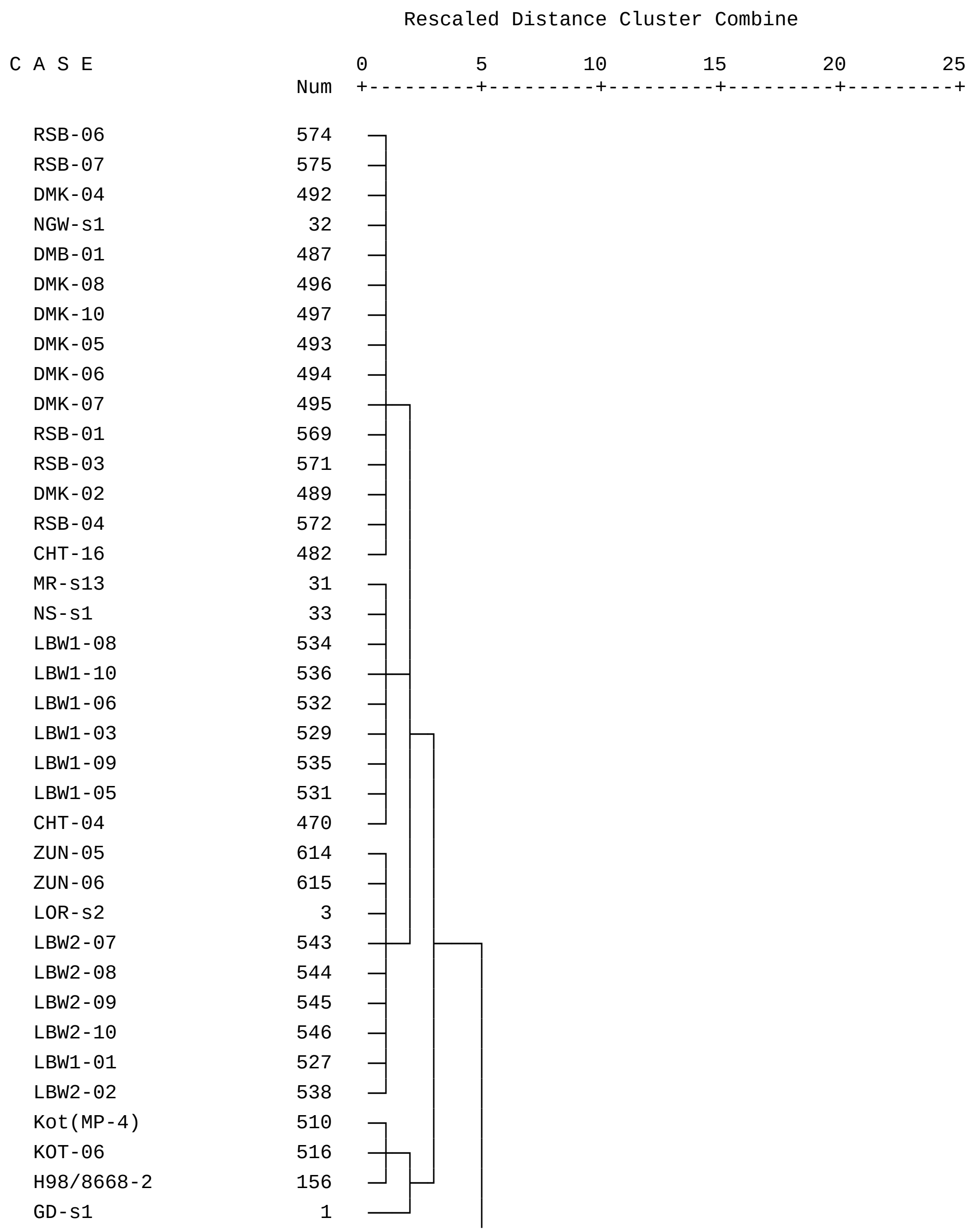
Figure 7.26	*Function 1*	*Function 2*
Log Al	.611	.670
Log Co	-.272	1.176
Log Cr	.079	-.450
Log Eu	.597	.371
Log Fe	.621	-1.218
Log La	.160	-.083
Log Mn	1.092	.018
Log Na	-1.241	-.088
Log Sc	-.073	.178
Log V	-.616	.098
Log Zn	.613	.273

Figure 7.28	*Function 1*	*Function 2*
Log Al	-1.462	-.304
Log Co	.189	1.060
Log Cr	-.985	-.069
Log Eu	-.209	-.704
Log Fe	.152	-1.252
Log La	.293	.155
Log Mn	.146	-.216
Log Na	-.497	.515
Log Sc	-.054	.646
Log V	1.808	.208
Log Zn	1.083	.689

Figure 7.29	*Function 1*	*Function 2*
Log Al	.082	.919
Log Co	-.097	-.316
Log Cr	-.194	-.547
Log Eu	.136	-.112
Log Fe	.067	1.018
Log La	-1.137	-.183
Log Mn	-.052	-1.084
Log Na	.201	.108
Log Sc	.884	.414
Log V	-.251	-.746
Log Zn	.383	.820

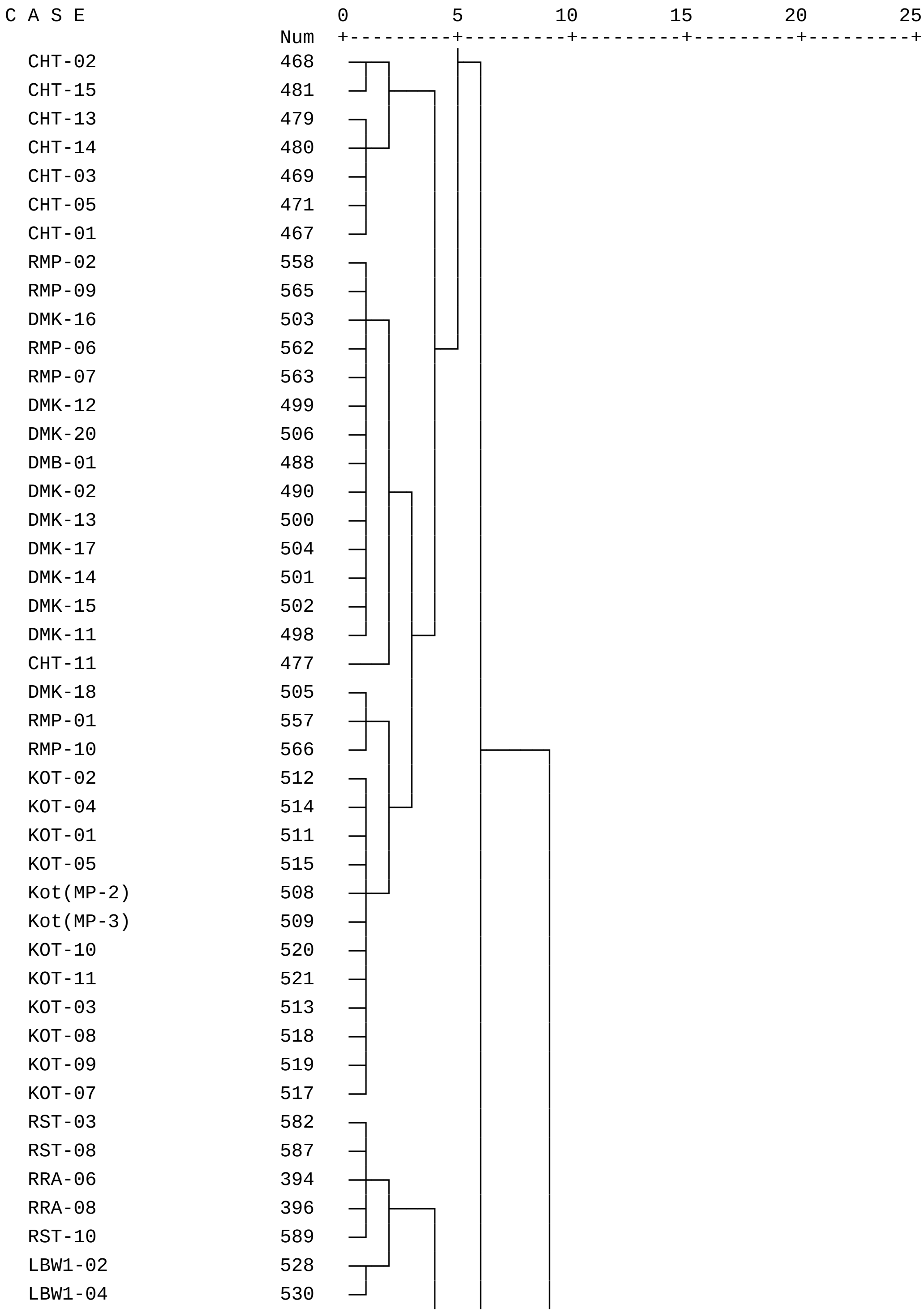
Appendix 7.9: Cluster Analysis (Complete linkage) of all steatite artifacts and geologic samples

Section A



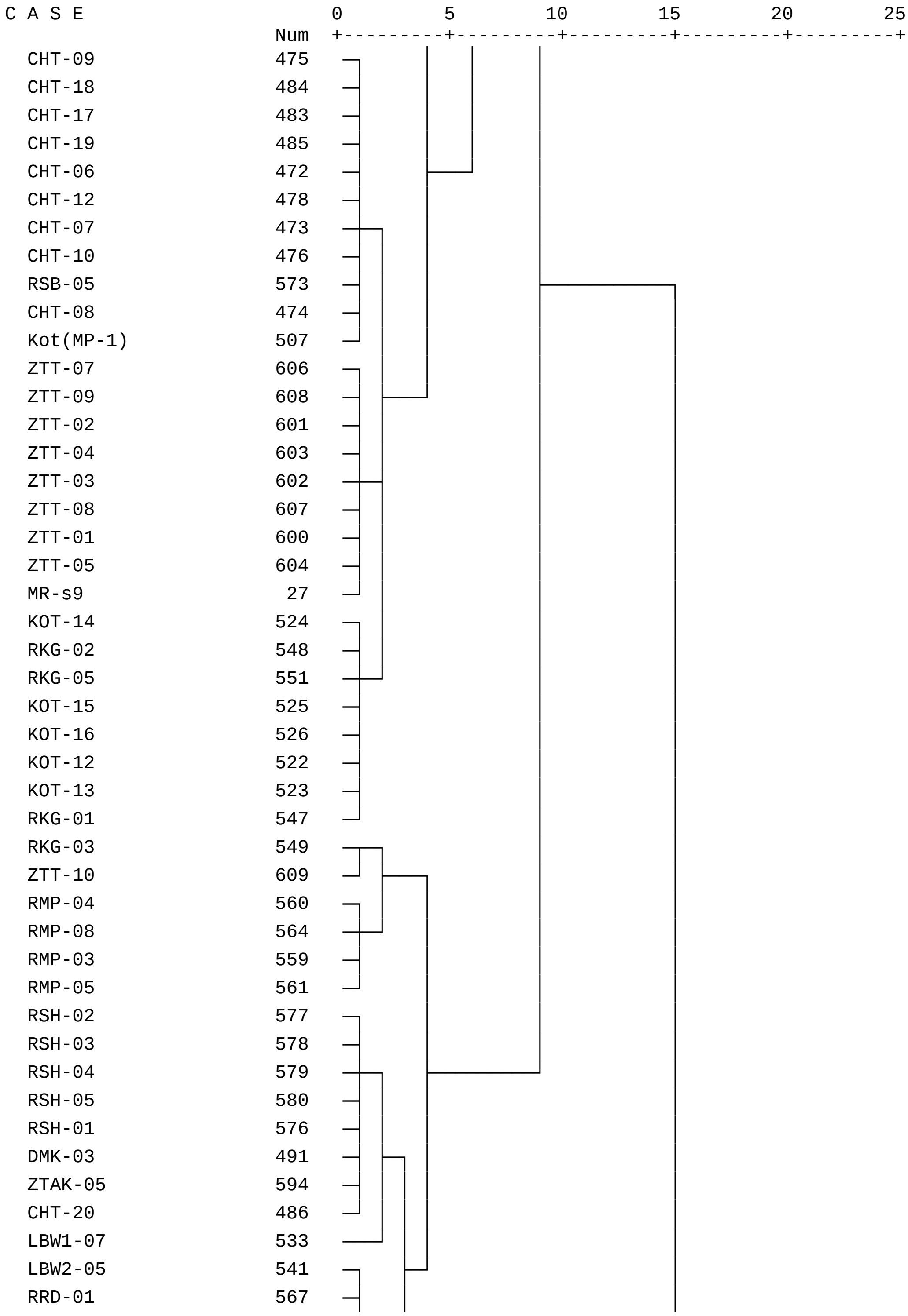
Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section B



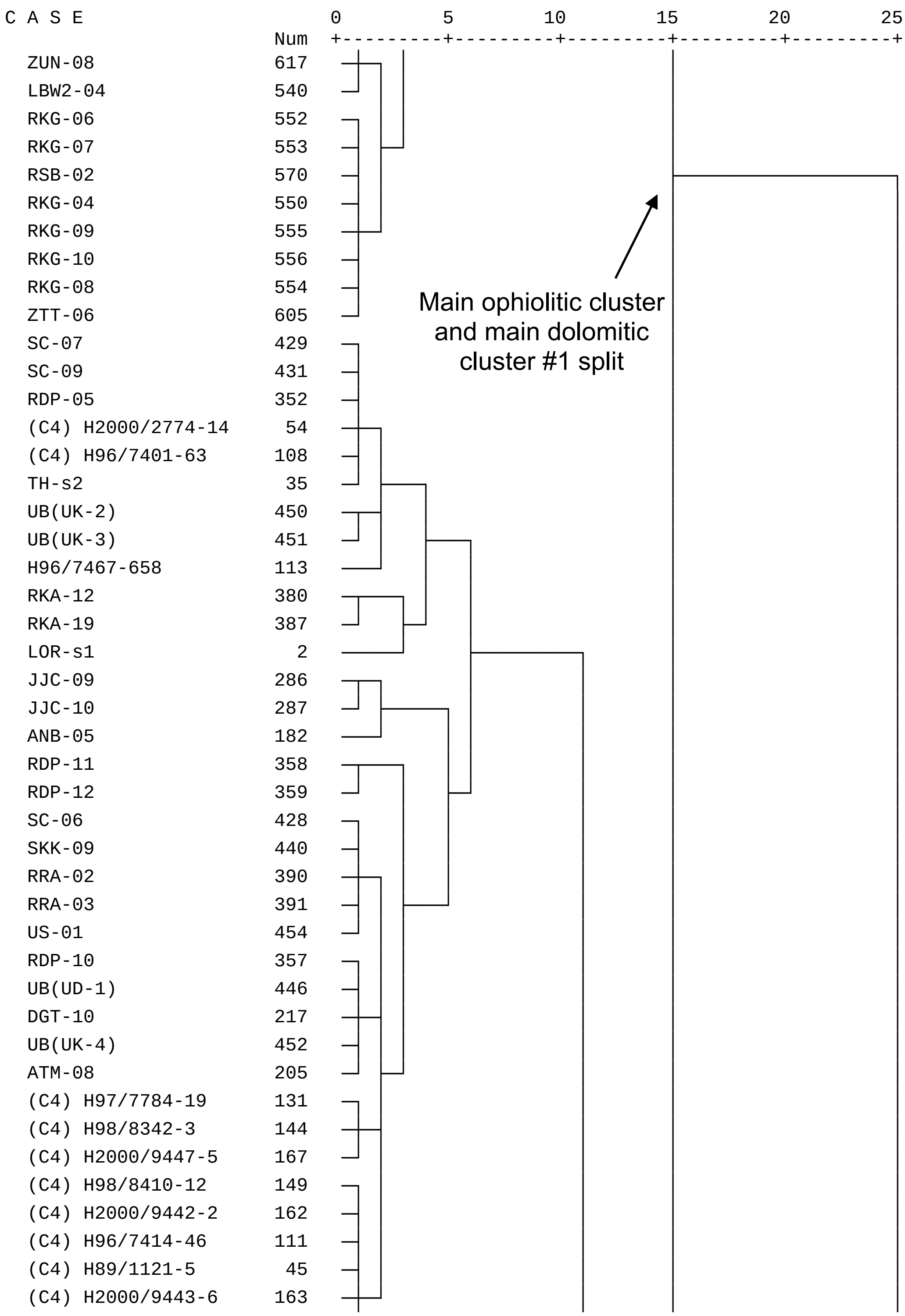
Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section C



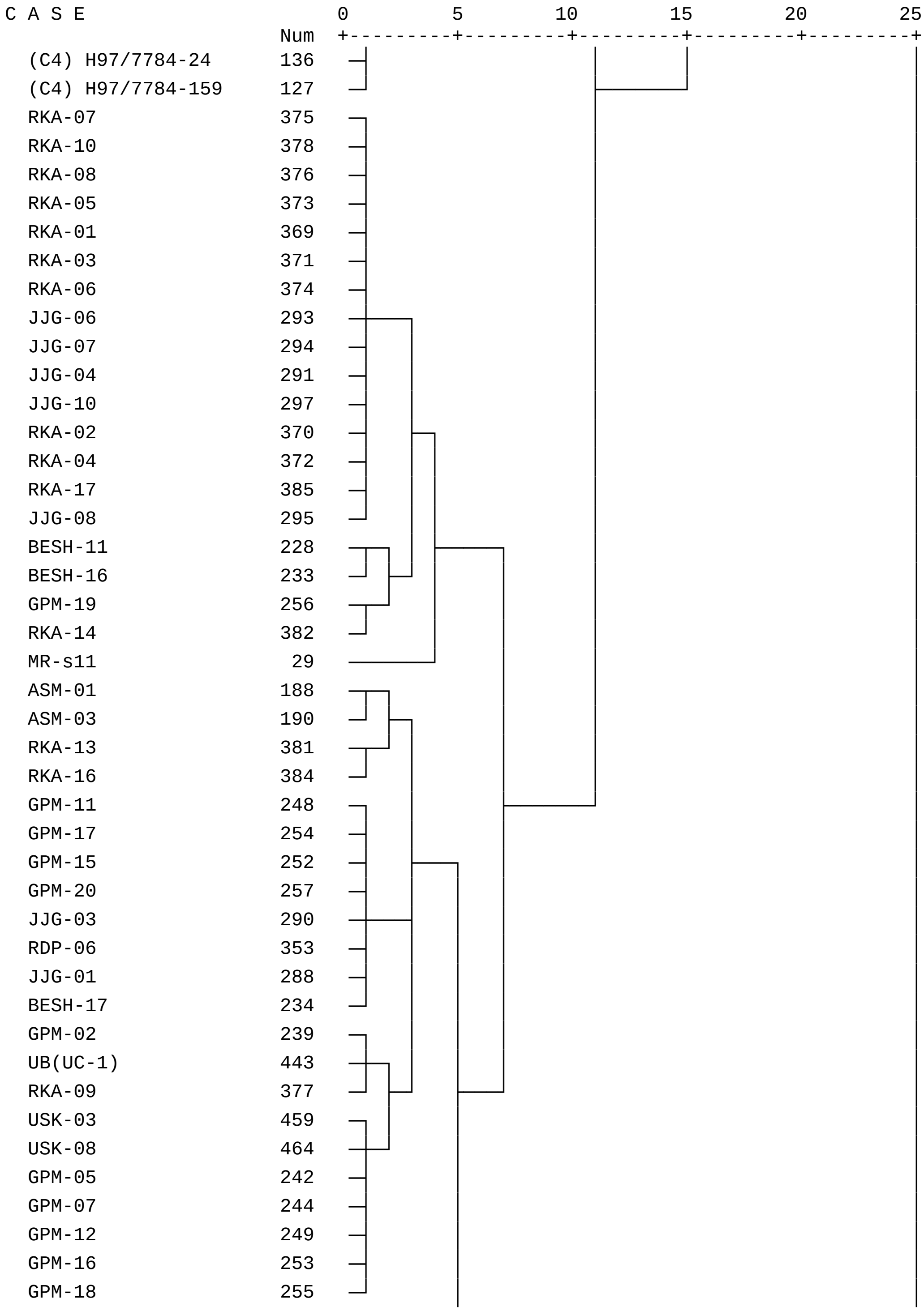
Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section D



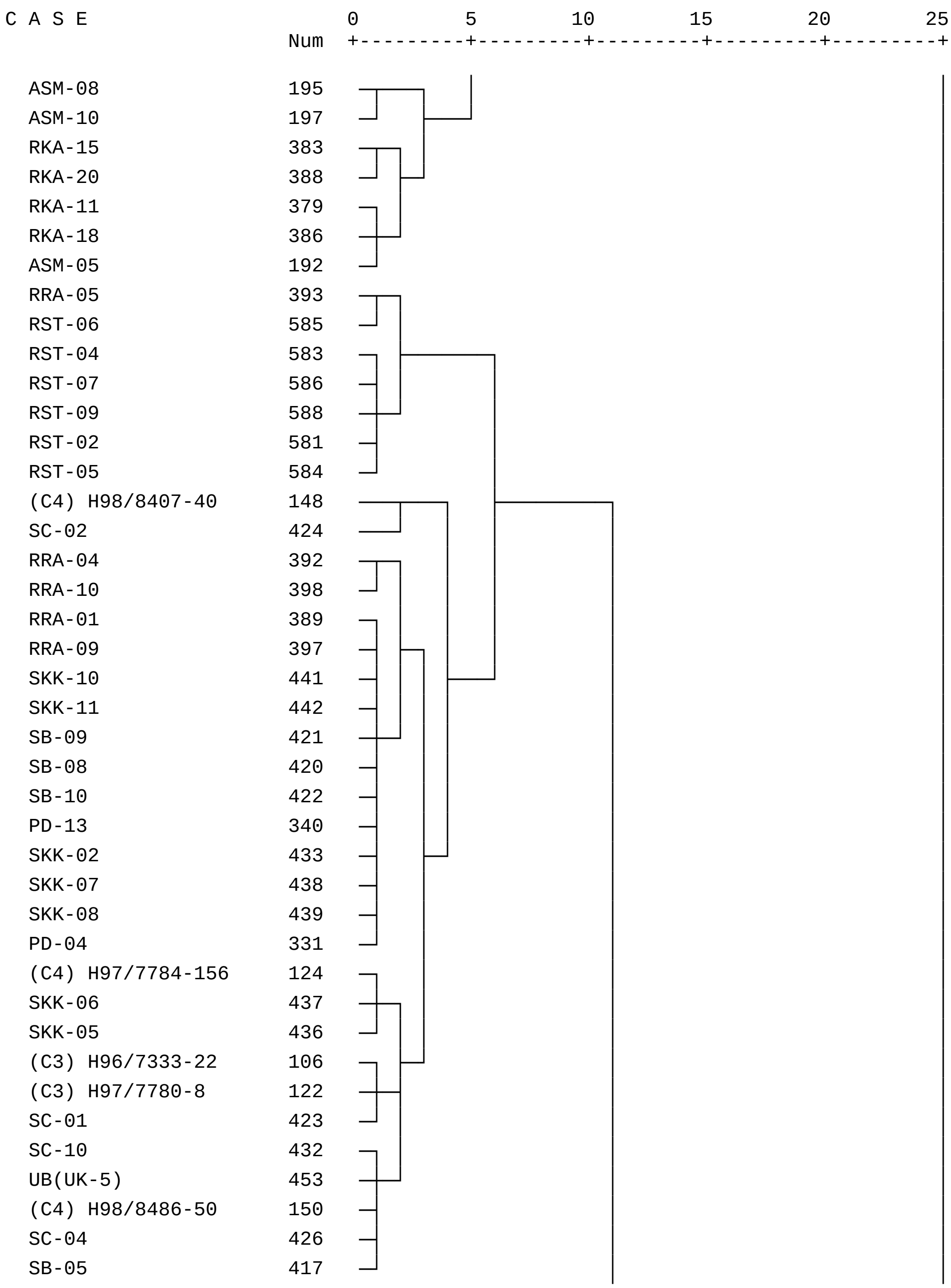
Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section E



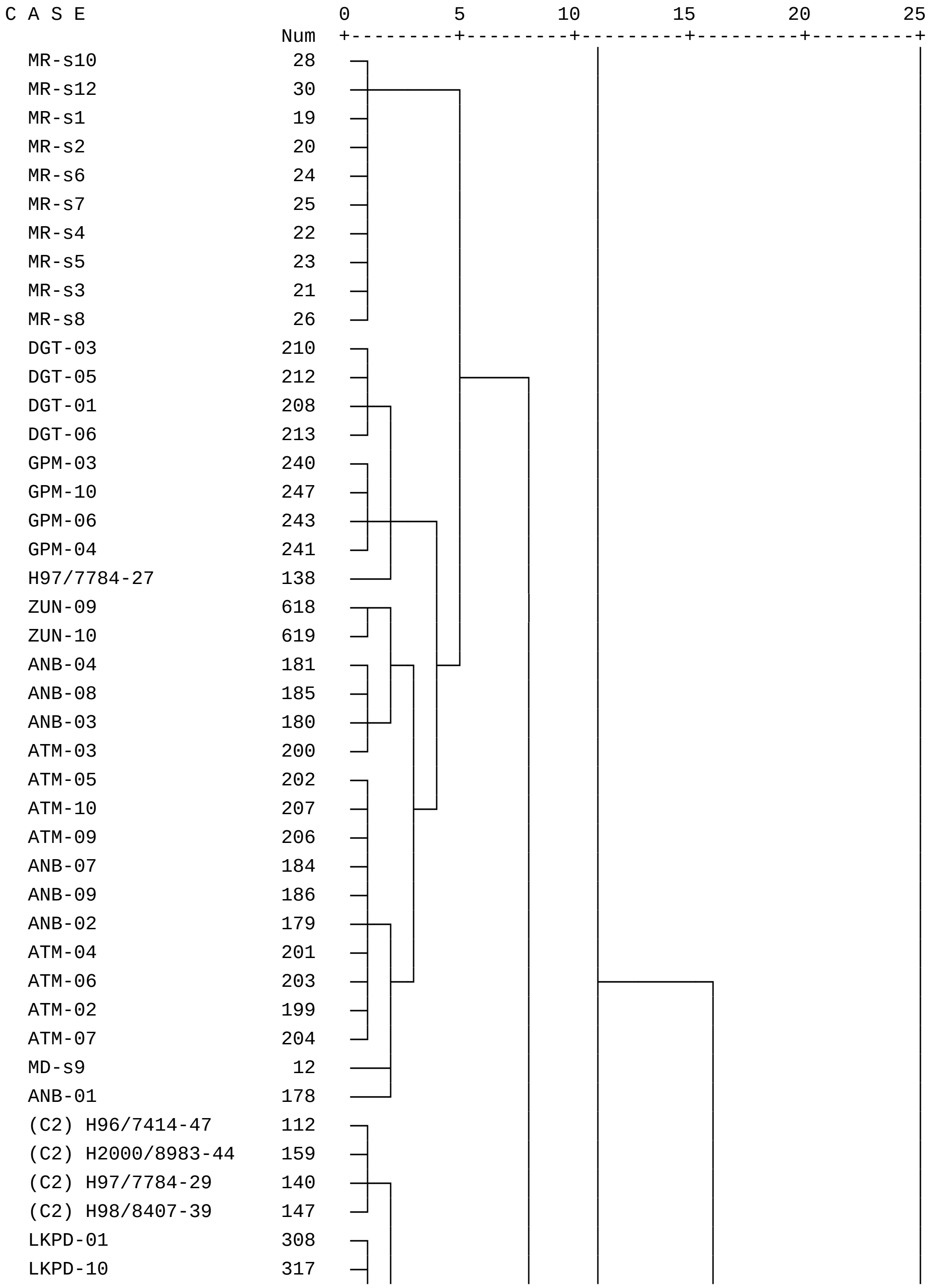
Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section F



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

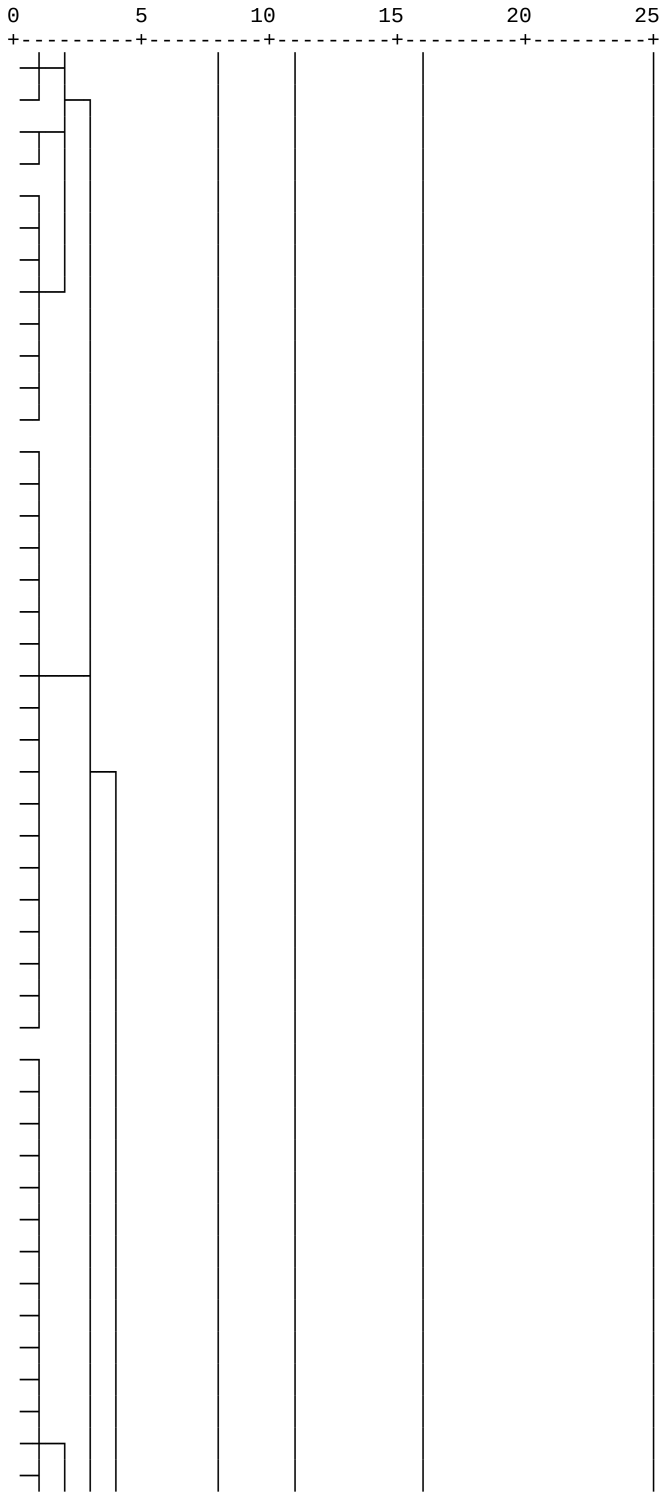
Section G



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section H

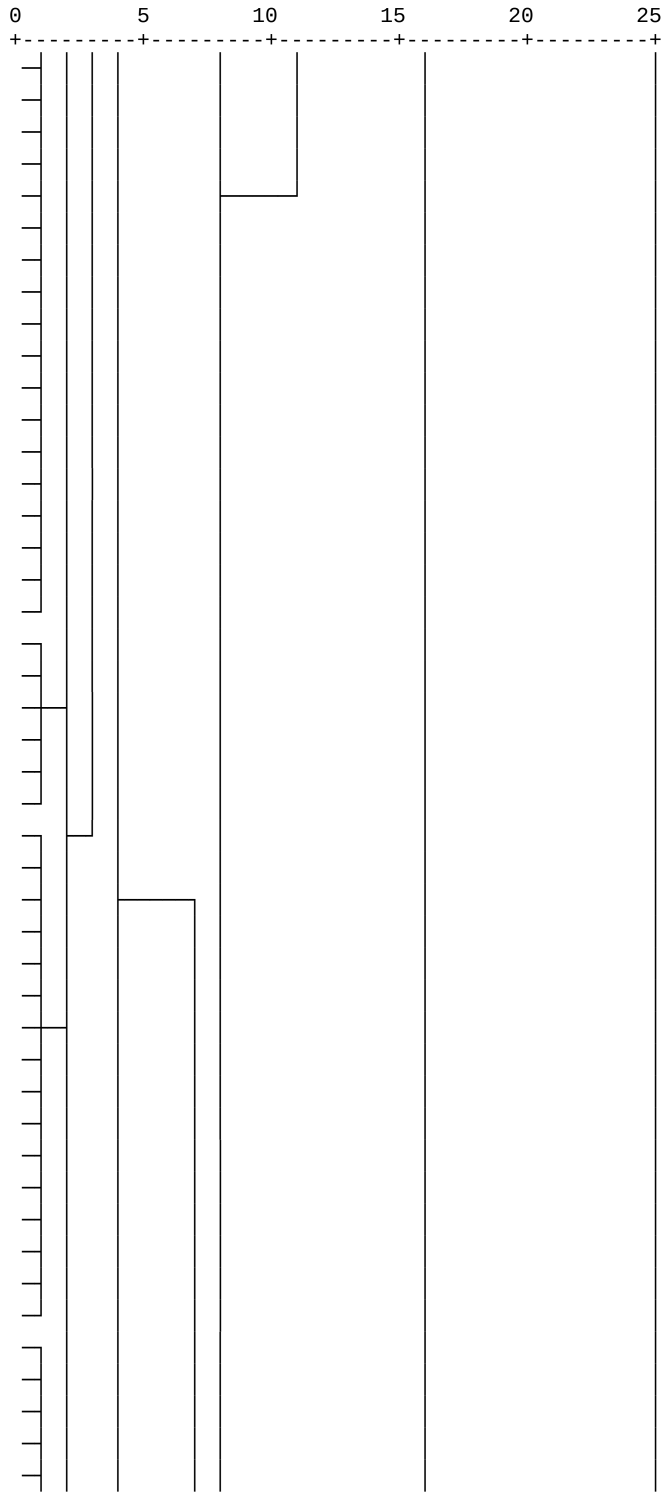
C A S E	Num
(C3) H95/5802-5	89
(C2) H2000/9973-13	174
RSA-12	410
RSA-14	412
JAMPT-03	260
JAMPT-20	277
JAMPT-01	258
(C1) H2000/2880-16	57
(C1) H95/6509-97	97
(C1) H95/4751-8	76
(C1) H96/7467-790	114
TH-s5	37
(C2) H95/4613-42	71
(C2) H96/7105-8	98
(C2) H2000/2230-16	48
(C2) H2000/8992-1	160
(C2) H2000/2301-176	50
(C2) H2000/2301-177	51
(C2) H97/7784-22	134
(C2) H97/7784-28	139
(C2) H99/8492-229	154
(C2) H96/7410-1	109
(C2) H99/8956-1	158
(C2) H97/7784-18	130
(C2) H97/7784-20	132
(C2) H2000/2230-17	49
(C2) H98/8487-32	151
(C2) H2000/8997-4	161
(C2) H97/7784-17	129
(C2) H97/7784-25	137
(C2) H2000/9443-7	164
PD-14	341
PD-19	346
PD-20	347
UB(UC-2)	444
(C1) H99/7649-42	120
(C1) H99/9779-4	172
(C1) H93/3710-16	66
(C1) H96/7156-14	102
(C1) H95/5713-145	83
(C1) H90/3068-50	63
(C1) H95/5734-31	84
(C1) H95/5763-19	88
(C1) H2001/2922-6	60
(C1) H93/3869-24	69



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section I

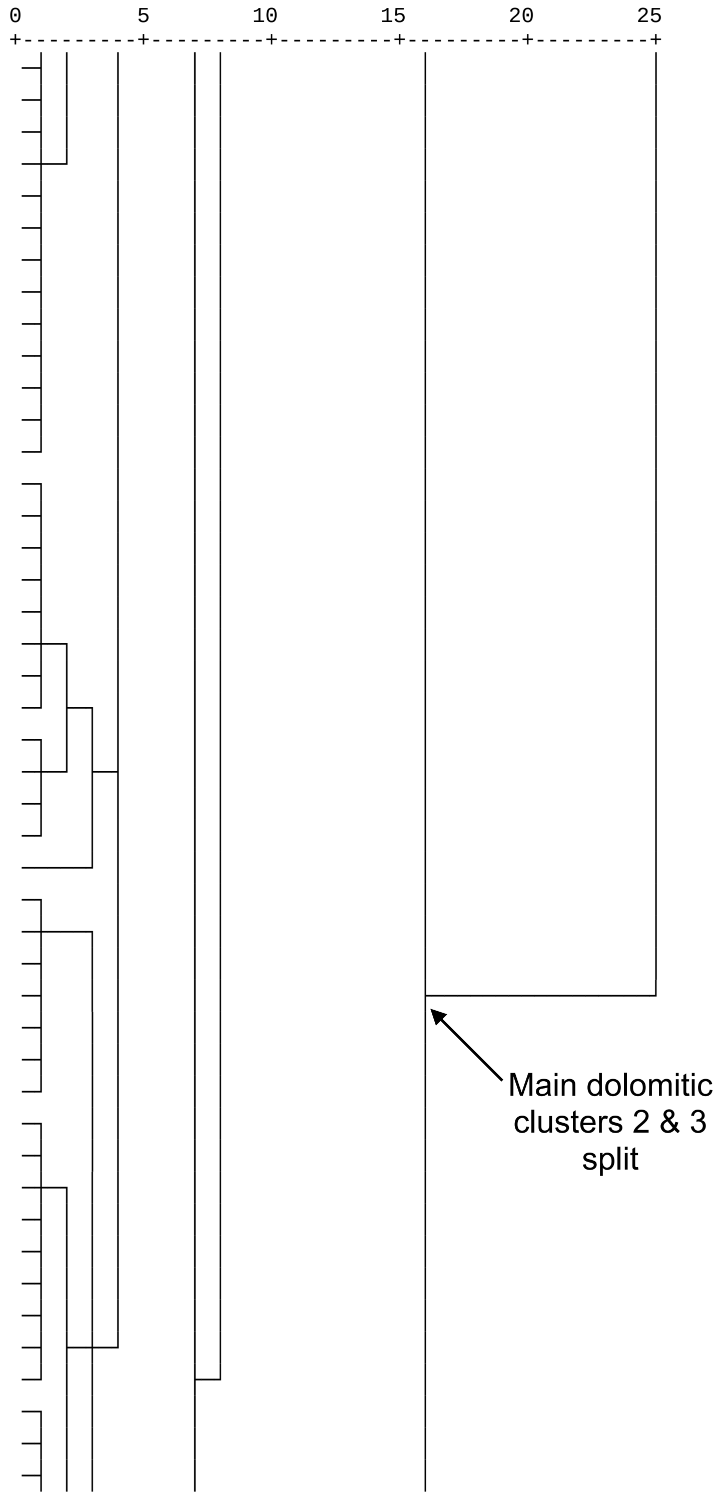
C A S E	Num
(C1) H95/5747-125	85
(C1) H95/5759-25	87
(C1) H95/4726-101	74
MD-s2	5
MD-s14	17
(C1) H96/7257-46	105
(C1) H2000/2753-17	53
(C1) H96/6219-44	94
(C1) H95/4950-4	78
(C1) H95/4961-176	80
(C1) H95/4954-18	79
(C1) H2000/2774-15	55
(C1) H2001/11923-9	177
(C1) H2000/9514-93	168
(C1) H2000/2789-30	56
(C1) H96/7256-43	104
(C1) H96/6218-8	93
MD-s7	10
(C1) H89/1018-13	44
PD-05	332
PD-18	345
PD-08	335
PD-15	342
PD-16	343
JAMPT-05	262
JAMPT-08	265
JAMPT-04	261
JAMPT-18	275
JAMPT-19	276
JAMPT-06	263
JAMPT-15	272
JAMPT-12	269
JAMPT-17	274
JAMPT-14	271
JAMPT-11	268
JAMPT-13	270
JAMPT-07	264
JAMPT-10	267
JAMPT-09	266
JAMPT-16	273
(C1) H90/3290-17	64
(C1) H98/8355-2	145
(C1) H93/3808-52	68
(C1) H95/4746-7	75
(C1) H95/5820-11a	91



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section J

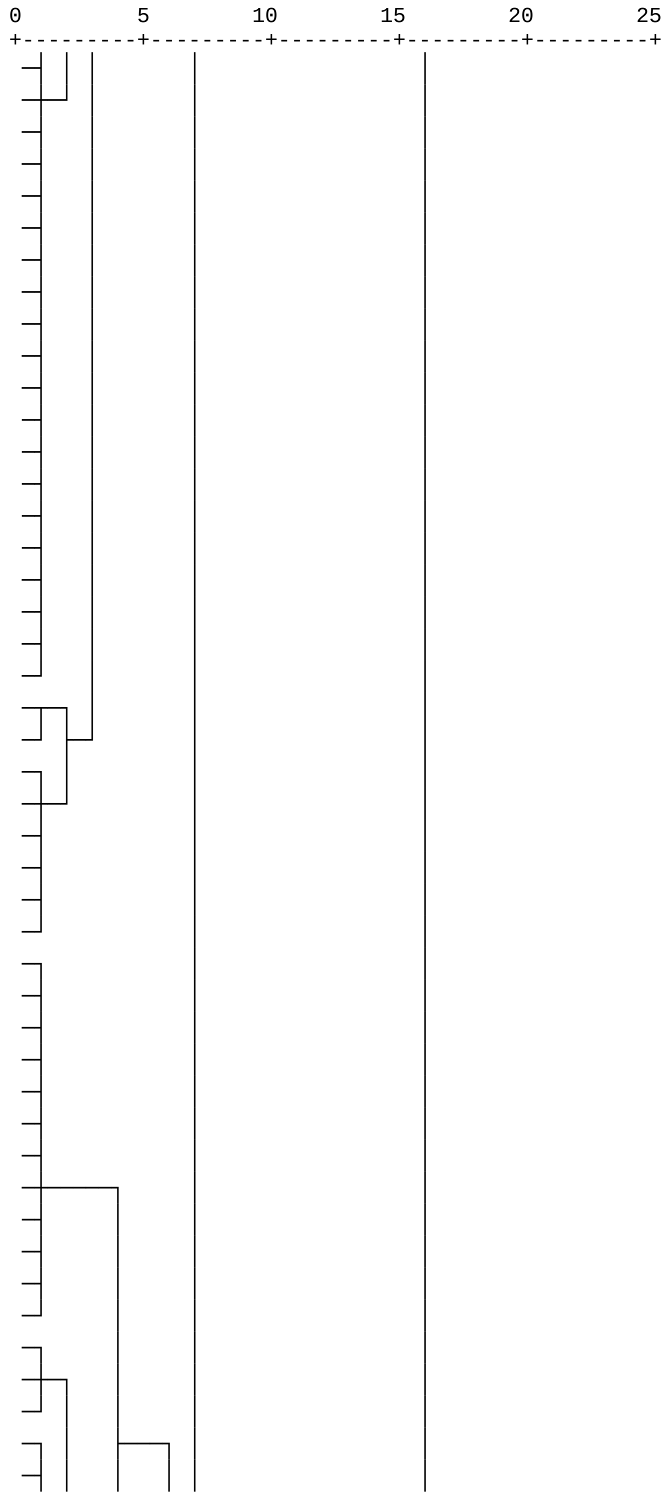
C A S E	Num
(C1) H99/9737-22	169
(C1) H97/7784-30	141
(C1) H95/4453-22	70
(C1) H99/9756-16	171
(C1) H95/5184-1	82
(C1) H96/6234-2	95
(C1) H2001/2920-7	59
(C1) H96/5837-18	92
(C1) H90/3030-55	62
(C1) H95/5749-97	86
(C1) H2001/2373-10	52
(C1) H96/6257-21	96
(C1) H97/7784-16	128
(C1) H2000/2230-14	46
(C1) H96/7410-2	110
(C1) H97/7784-23	135
(C1) H97/7619-3	116
(C1) H97/7784-21	133
(C1) H2000/2230-15	47
(C1) H94/5135-34	81
(C1) H98/8487-33	152
(C3) H99/8490-103	153
(C3) H2000/9445-2	166
(C3) H97/7784-31	142
UB(UD-2)	447
SKK-04	435
(C1) H88/340-24	43
ZUN-01	610
PD-12	339
PD-17	344
UB(UK-1)	449
ZUN-02	611
PD-11	338
SB-03	415
SKK-03	434
SB-02	414
(C1) H2000/11001-6	175
(C1) H2001/11562-26	176
SB-04	416
SC-08	430
SB-06	418
SC-03	425
(C3) H97/7780-10	121
(C3) H98/8364-5	146
LKPD-17	324



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section K

C A S E	Num
MD-s12	15
MD-s15	18
MD-s11	14
(C1) H96/7239-26	103
MD-s1	4
(C1) H93/3534-13	65
(C1) H96/7358-11	107
(C1) H96/7153-14	101
(C1) H99/9747-33	170
(C1) H95/4615-94	72
(C1) H2001/2913-12	58
(C1) H87/33-02	38
(C1) H87/237-86	42
(C1) H97/7780-9	123
MD-s6	9
MD-s8	11
MD-s4	7
(C1) H96/7531-16	115
MD-s3	6
MD-s5	8
US-02	455
US-03	456
PD-09	336
PD-10	337
PD-01	328
PD-06	333
PD-03	330
PD-07	334
RDV-08	366
RDV-10	368
RRA-07	395
RSA-01	399
RSA-02	400
RDV-01	360
RDV-09	367
RDV-05	363
RDV-07	365
RDV-06	364
RDV-03	361
RDV-04	362
RSA-07	405
RSA-10	408
TH-s3	36
BESH-03	220
BESH-06	223

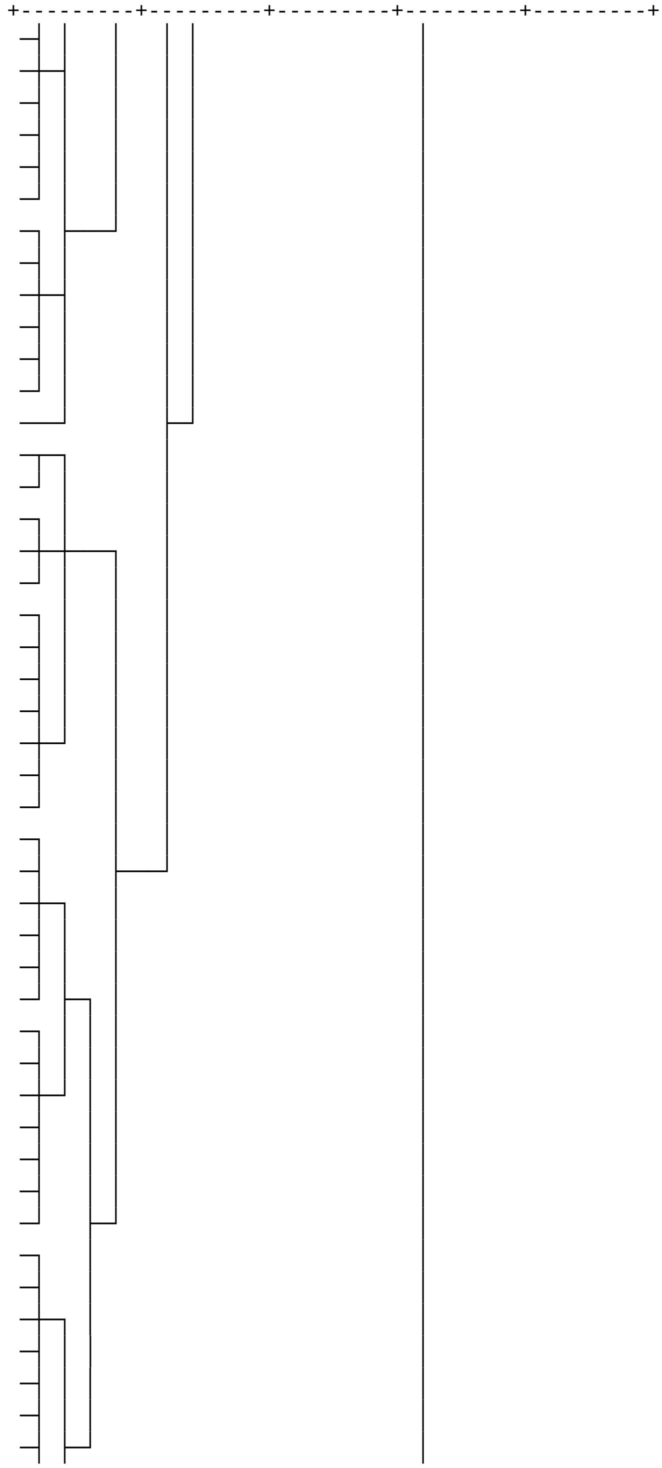


Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section L

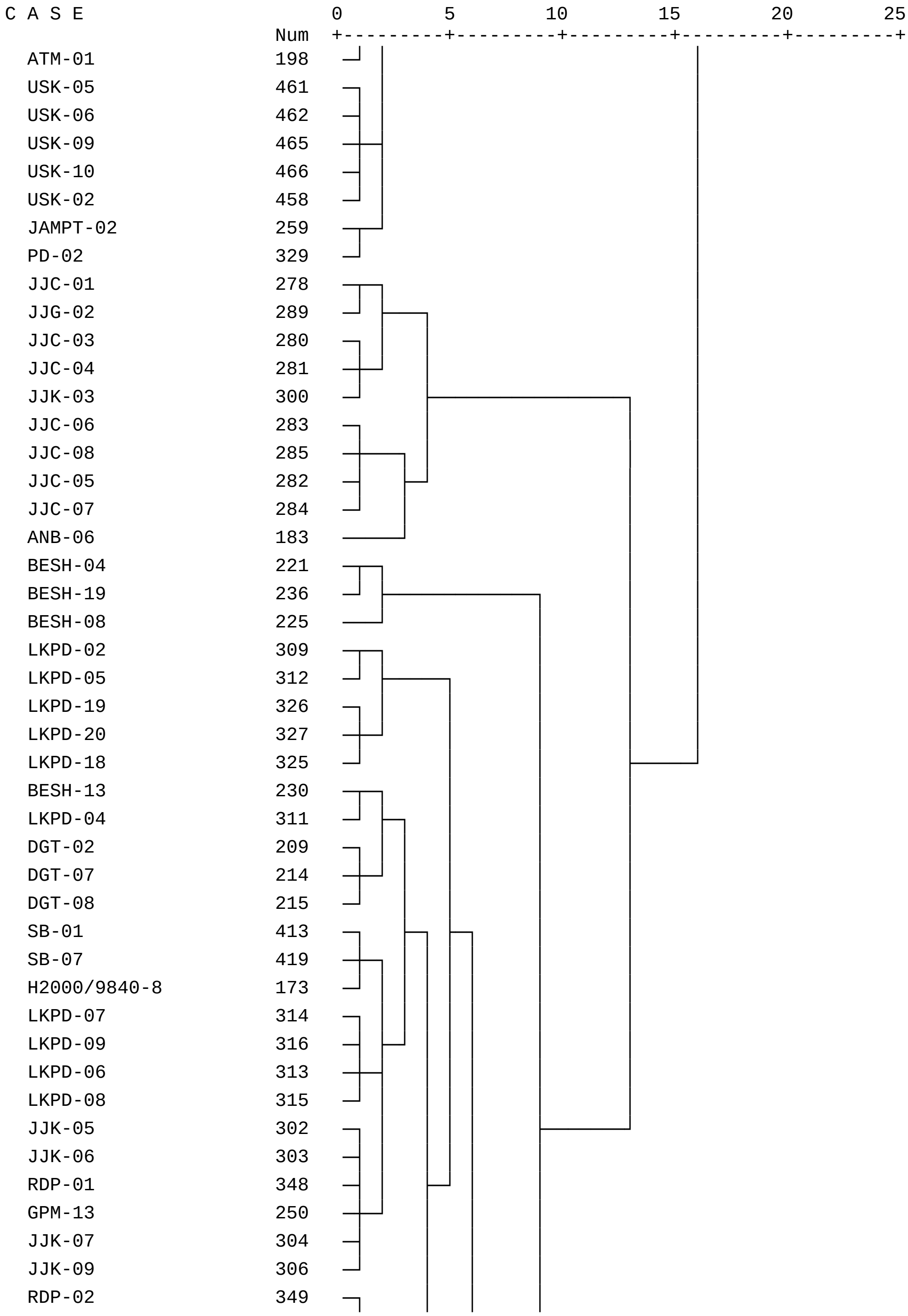
Rescaled distance: 0, 5, 10, 15, 20, 25

C A S E	Num
LKPD-12	319
LKPD-14	321
BESH-07	224
BESH-01	218
BESH-02	219
UB(UD-3)	448
BESH-15	232
BESH-18	235
BESH-12	229
BESH-14	231
TH-s1	34
RSA-11	409
BESH-09	226
GPM-08	245
GPM-14	251
ZTAK-01	590
ZTAK-03	592
ZTAK-02	591
RSA-04	402
RSA-06	404
RSA-03	401
RSA-05	403
RSA-09	407
RSA-08	406
USK-04	460
ZTAK-07	596
ZTAK-10	599
ZTAK-06	595
ZTAK-08	597
ZTAK-09	598
ZTAK-04	593
RRD-02	568
ZUN-04	613
LBW2-01	537
LBW2-03	539
LBW2-06	542
ZUN-03	612
ZUN-07	616
USK-01	457
USK-07	463
RDP-04	351
RDP-08	355
RDP-09	356
RDP-03	350
ANB-10	187



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

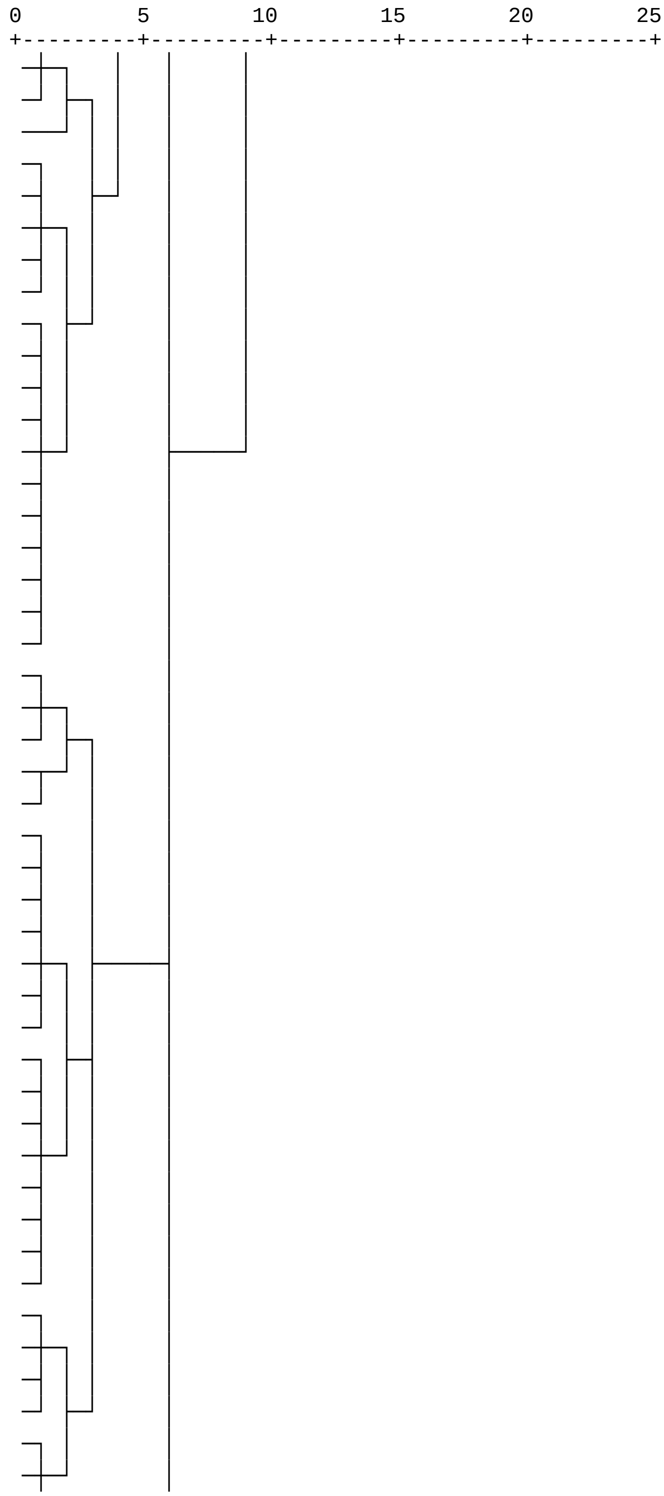
Section M



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section N

C A S E	Num
RDP-07	354
UB(UC-3)	445
GPM-01	238
ASM-04	191
ASM-06	193
ASM-07	194
ASM-09	196
ASM-02	189
JJG-05	292
JJG-09	296
JJK-04	301
JJK-10	307
JJK-08	305
JJK-02	299
DGT-04	211
DGT-09	216
BESH-20	237
JJC-02	279
GPM-09	246
(C3) H97/7784-157	125
RSA-13	411
BESH-10	227
(C3) H97/7784-158	126
LKPD-03	310
(C3) H99/7638-1	119
(C3) H99/7794-3	143
(C3) H87/86-229	40
(C3) H87/86-236	41
(C3) H87/86-228	39
(C3) H93/3710-70	67
(C3) H99/8760-77	157
LKPD-13	320
LKPD-15	322
JJK-01	298
(C3) H99/7636-8	117
(C3) H99/7637-32	118
SC-05	427
MD-s10	13
BESH-05	222
LKPD-11	318
LKPD-16	323
(C3) H2001/2939-25	61
(C3) H95/5803-25	90
MD-s13	16
(C3) H95/4919-62	77



Appendix 7.9 (cont): Cluster Analysis (Complete linkage) of all geologic samples and artifacts

Section O

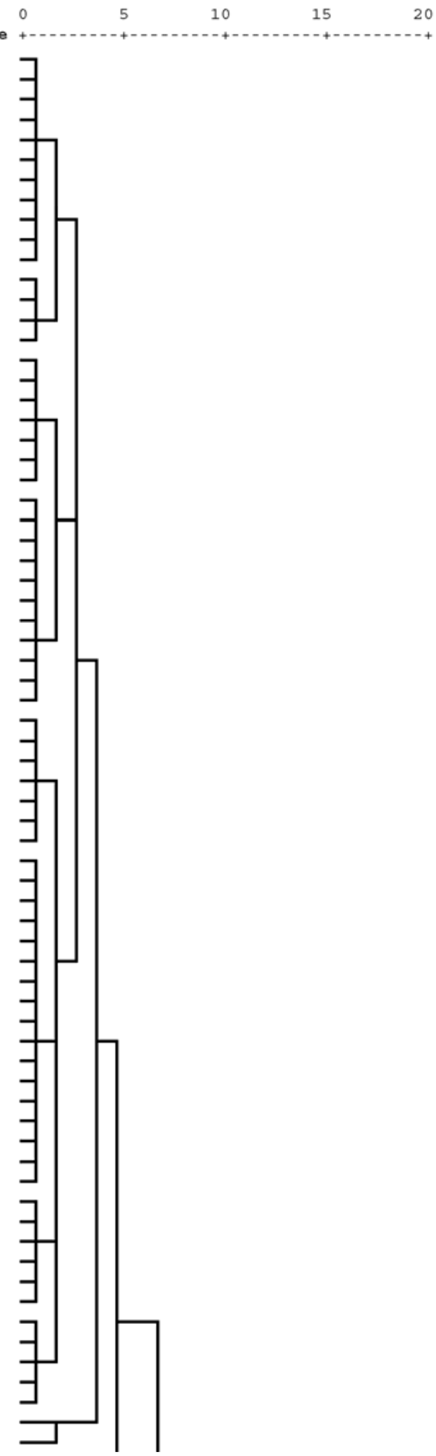
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C A S E                        0         5        10        15        20        25
                        Num  +---------+---------+---------+---------+---------+

  (C3) H96/7106-27       99   ─┐         │
  (C3) H96/7118-9       100   ─┤         │
  (C3) H95/4723-2        73   ─┤         │
  (C3) H99/8497-3       155   ─┘         │
  H2000/9445-1          165   ───────────┘
```

Appendix 7.10: Cluster Analysis (Complete linkage) of 140 steatite artifacts from Harappa

Section A

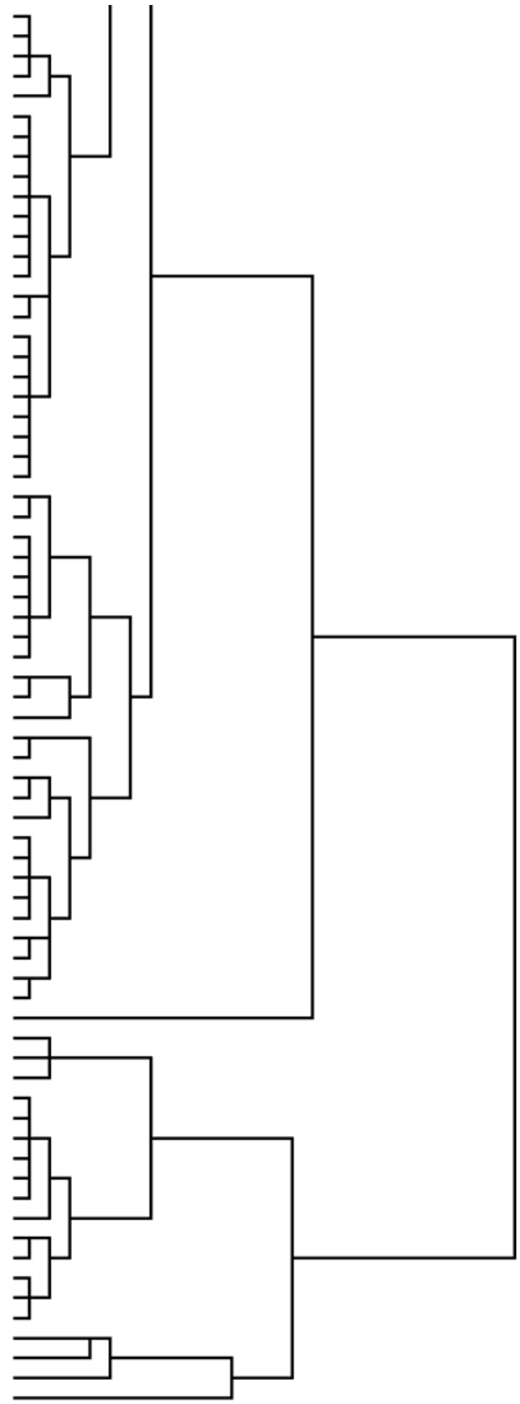
Artifact #	Period	Mound	Trench	11 dolomitic 1st / 2nd PGM	Type
H2000/2753-17	3C	E	Tr.55	PD / SB	E
H96/6219-44	S&D	ET	Tr.35	SB / SKK	D
H95/4950-4	3C	ET	Tr.28	SKK / SB	A
H95/4961-176	3C	ET	Tr.28	SKK / SB	A
H95/4954-18	3C	ET	Tr.28	SKK / SB	E
H2000/2774-15	3C	E	Tr.55	SKK / PD	C
H2001/11923-9	3C	E	Tr.11	SB / SKK	C
H2000/9514-93	2	AB	Tr.39	SB / JAMPT	E
H2000/2789-30	3C	E	Tr.55	SKK / SB	C
H96/7256-43	3B	F	Tr.37	SKK / SB	B
H96/6218-8	S&D	ET	Tr.35	SKK / SB	C
H96/7239-26	3C	F	Tr.37	SB / SC	A
H2001/11562-26	S&D	E	Tr.11	SB / SC	F
H96/7531-16	1	AB	Tr.39	ATM / SKK	A
H96/7257-46	3B	F	Tr.37	PD / SKK	B
H90/3290-17	S&D	E	Tr.59	SB / SKK	D
H98/8355-2	3B	AB	Tr.39	SKK / SB	A
H93/3808-52	S&D	E	Tr.5	SKK / SB	A
H95/4746-7	3C	ET	Tr.19	SB / SKK	A
H95/5820-11a	3C	ET	Tr.28	PD / SKK	A
H99/9737-22	3C	F	Tr.43	SKK / SB	A
H97/7784-30	3A	AB	Tr.42	SKK / SB	E
H95/4453-22	S&D	E	Tr.11	SB / SKK	D
H99/9756-16	3C	F	Tr.43	SB / SKK	A
H95/5184-1	3C	E	Tr.7/8	SB / SKK	A
H96/6234-2	S&D	ET	Tr.35	SB / SKK	C
H2001/2920-7	S&D	E	Tr.57	SKK / SB	C
H96/5837-18	3C	ET	Tr.28	SB / LKPD	B
H90/3030-55	S&D	E	Tr.58	JAMPT / RSA	E
H95/5749-97	3C	ET	Tr.32	SKK / SB	C
H2001/2373-10	3B	E	Tr.54	SKK / SB	C
H96/6257-21	3C	ET	Tr.35	SKK / SB	A
H97/7784-16	3A	AB	Tr.42	RSA / SKK	A
H2000/2230-14	3B	E	Tr.54	SB / LKPD	C
H96/7410-2	2/3	AB	Tr.39	SKK / SB	E
H97/7784-23	3A	AB	Tr.42	SKK / SB	C
H97/7619-3	3C	F	Tr.41	SB / LKPD	C
H97/7784-21	3A	AB	Tr.42	SB / SKK	B
H2000/2230-15	3B	E	Tr.54	LKPD / SB	C
H94/5135-34	3C	E	Tr.7/8	SB / SC	E
H99/7649-42	3C	F	Tr.41	SB / SKK	A
H99/9779-4	3C	F	Tr.43	SB / LKPD	A
H93/3710-16	3C	E	Tr.3	SB / SKK	F
H96/7156-14	3C	E	Tr.36	SB / SKK	G
H95/5713-145	S&D	ET	Tr.32	SB / SKK	C
H90/3068-50	S&D	E	Tr.58	SB / SKK	A
H95/5734-31	3C	ET	Tr.32	PD / SB	C
H95/5763-19	3C	ET	Tr.32	SB / LKPD	A
H2001/2922-6	S&D	E	Tr.57	SB / SKK	A
H93/3869-24	3C	E	Tr.7	SKK / PD	A
H95/5747-125	3C	ET	Tr.32	SB / SKK	B
H95/5759-25	3C	ET	Tr.32	SB / PD	E
H95/4726-101	3C	ET	Tr.19	SB / SKK	A
H87/33-02	3C	CEM	CEM	SB / SKK	F
H87/237-86	S&D	CEM	CEM	SB / SKK	F
H97/7780-9	3B	AB	Tr.42	SB / SKK	A
H89/1018-13	S&D	AB/E	Tr.53	SKK / SB	D
H93/3534-13	S&D	E	Tr.2	LKPD / SB	F
H96/7358-11	5	AB	Tr.38	LKPD / SKK	A
H96/7153-14	S&D	E	Tr.36	SB / SKK	D
H99/9747-33	3C	F	Tr.43	SKK / SB	B
H95/4615-94	3C	ET	Tr.10	SKK / SB	A
H2001/2913-12	3B	E	Tr.57	SKK / SB	E
H2000/2880-16	3C	E	Tr.55	SKK / SB	D
H95/6509-97	2	E/ET	Tr.11	JAMPT / RSA	B
H95/4751-8	3C	ET	Tr.19	SKK / SB	E
H96/7467-790	S&D	AB	Tr.39	SKK / SB	A
H2000/11001-6	1	AB	Tr.39	JAMPT / RSA	A
H88/340-24	S&D	E	Op. 3	PD / SB	F
H98/8487-33	2	AB	Tr.39	PD / SKK	A



Appendix 7.10 (cont): Cluster Analysis (Complete linkage) of 140 steatite artifacts from Harappa

Section B

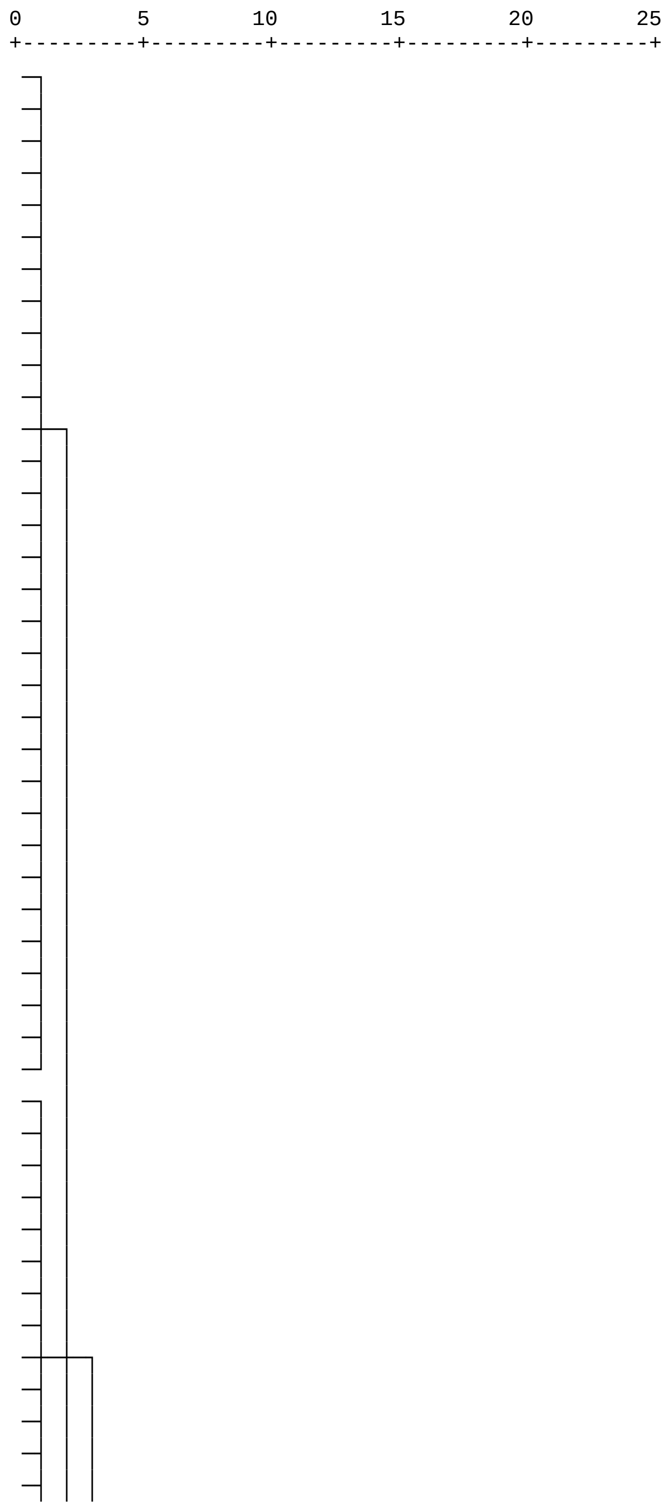
H96/7414-47	2	AB	Tr.39	JAMPT / LKPD	A
H2000/8983-44	2	AB	Tr.39	SC / LKPD	E
H97/7784-29	3A	AB	Tr.42	SC / SKK	B
H98/8407-39	2	AB	Tr.39	RDP / USK	E
H2000/9973-13	2	AB	Tr.39	JAMPT / RSA	C
H95/4613-42	3B	ET	Tr.10	SKK / SB	A
H96/7105-8	3C	E	Tr.36	SKK / SB	A
H2000/2230-16	3B	E	Tr.54	JAMPT / RSA	C
H2000/8992-1	2	AB	Tr.39	JAMPT / RSA	E
H2000/2301-176	3A	E	Tr.54	JAMPT / SB	B
H2000/2301-177	3A	E	Tr.54	JAMPT / SB	B
H97/7784-22	3A	AB	Tr.42	JAMPT / SKK	C
H97/7784-28	3A	AB	Tr.42	SB / SKK	B
H99/8492-229	2	AB	Tr.39	SKK / SC	E
H96/7410-1	2/3A	AB	Tr.39	SKK / SB	E
H99/8956-1	2	AB	Tr.39	SKK / JAMPT	A
H97/7784-18	3A	AB	Tr.42	USK / SKK	A
H97/7784-20	3A	AB	Tr.42	USK / SKK	A
H2000/2230-17	3B	E	Tr.54	JAMPT / SKK	B
H98/8487-32	2	AB	Tr.39	JAMPT / SKK	E
H2000/8997-4	2	AB	Tr.39	JAMPT / SKK	A
H97/7784-17	3A	AB	Tr.42	SKK / JAMPT	A
H97/7784-25	3A	AB	Tr.42	SKK / JAMPT	A
H2000/9443-7	3B	AB	Tr.39	JAMPT / USK	B
H99/7636-8	3C	F	Tr.41	RSA / LKPD	E
H99/7637-32	3C	F	Tr.41	LKPD / SB	G
H99/7638-1	3C	F	Tr.41	SB / JAMPT	G
H99/7794-3	3C	AB	Tr.42	SB / LKPD	B
H87/86-229	3C	CEM	CEM	SB / RSA	F
H87/86-236	3C	CEM	CEM	SB / LKPD	F
H87/86-228	3C	CEM	CEM	SB / SC	F
H93/3710-70	3C	E	Tr.3	LKPD / SB	F
H99/8760-77	3C	F	Tr.43	ANB /RSA	F
H95/5802-5	3C	ET	Tr.28	LKPD / RSA	A
H97/7784-157	3A	AB	Tr.42	LKPD / RSA	F
H97/7784-158	3A	AB	Tr.42	LKPD / SB	A
H2001/2939-25	3B	E	Tr.57	LKPD / RDP	G
H95/5803-25	3C	ET	Tr.28	LKPD / RSA	B
H99/8490-103	2	AB	Tr.39	SC / SKK	B
H2000/9445-2	3B	AB	Tr.39	SC / LKPD	G
H97/7784-31	3A	AB	Tr.42	SC / LKPD	A
H96/7106-27	3C	E	Tr.36	LKPD / RDP	G
H96/7118-9	3C	E	Tr.36	LKPD / RDP	A
H95/4723-2	3C	ET	Tr.19	LKPD / RDP	B
H99/8497-3	2	AB	Tr.39	LKPD / SC	E
H95/4919-62	3C	ET	Tr.28	RDP / SC	D
H97/7780-10	3B	AB	Tr.42	SB / SC	E
H98/8364-5	3B	AB	Tr.39	SB / SC	F
H96/7333-22	5	AB	Tr.38	SC / SKK	A
H97/7780-8	3B	AB	Tr.42	SC / SB	A
H2000/9445-1	3B	AB	Tr.39	ANB / ATM	G
H97/7784-156	3A	AB	Tr.42	SKK / SC	A
H98/8407-40	2	AB	Tr.39	SC / SKK	A
H98/8486-50	2	AB	Tr.39	SKK / SC	A
H98/8410-12	2	AB	Tr.39	SC / SKK	A
H2000/9442-2	3B	AB	Tr.39	SC / SKK	E
H96/7414-46	2	AB	Tr.39	SC / SKK	A
H89/1121-5	S&D	E	Tr.52	SKK / SC	A
H2000/9443-6	3B	AB	Tr.39	SKK / SC	A
H97/7784-24	3A	AB	Tr.42	SKK / SC	C
H97/7784-159	3A	AB	Tr.42	SKK / SC	A
H2000/2774-14	3C	E	Tr.55	SC / RDP	G
H96/7401-63	S&D	AB	Tr.39	SC / RDP	F
H97/7784-19	3A	AB	Tr.42	SC / SKK	A
H98/8342-3	3C	AB	Tr.39	SC / SKK	F
H2000/9447-5	3B	AB	Tr.39	SC / SKK	A
H97/7784-27	3A	AB	Tr.42	LBW1 / LBW2	A
H2000/9840-8	3C	F	Tr.43	SB / SC	E
H98/8668-2	3C	F	Tr.43	KOT / ZTT	E
H96/7467-658	S&D	AB	Tr.39	ATM / SC	A



Appendix 7.11: Cluster Analysis (Complete linkage) of all 177 steatite artifacts

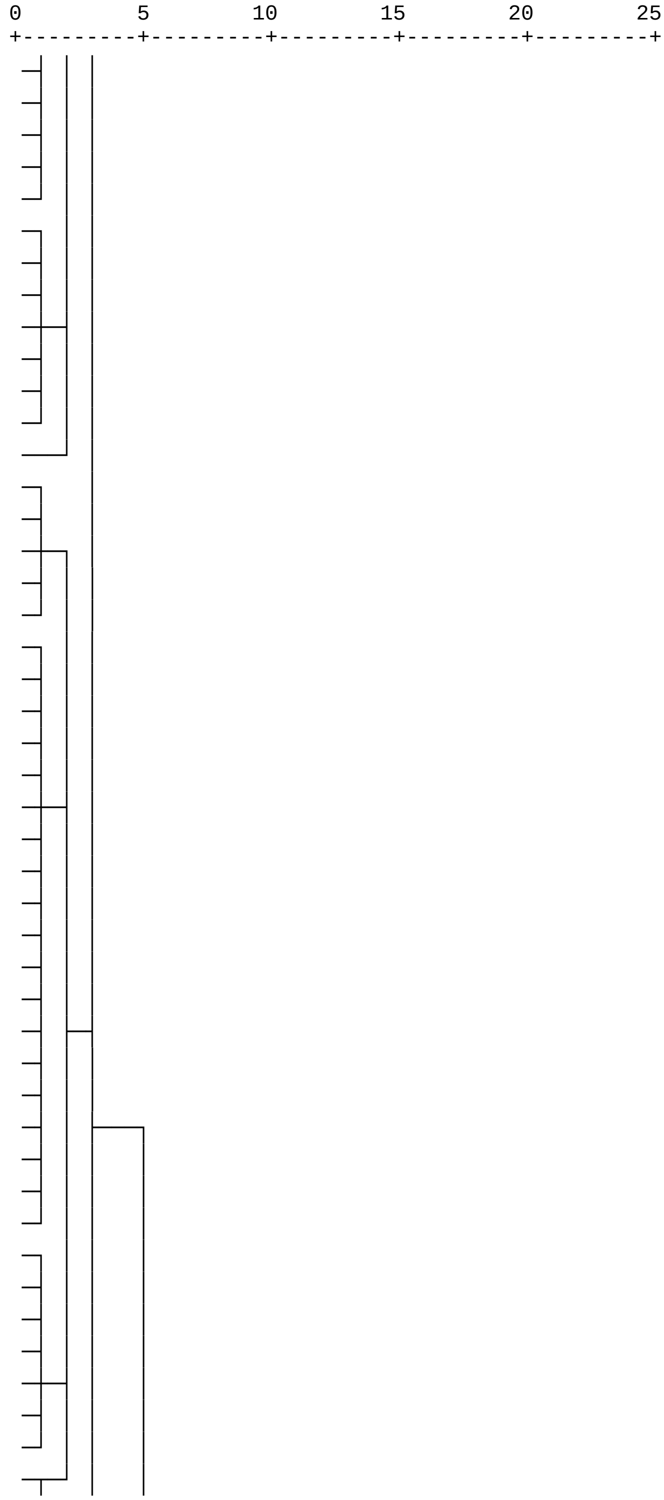
Section A

C A S E	Num
(C1) H2000/2753-17	53
(C1) H96/6219-44	94
(C1) H95/4950-4	78
(C1) H95/4961-176	80
(C1) H95/4954-18	79
(C1) H2000/2774-15	55
(C1) H2001/11923-9	177
(C1) H2000/9514-93	168
(C1) H2000/2789-30	56
(C1) H96/7256-43	104
(C1) H96/6218-8	93
MD-s7	10
MD-s2	5
MD-s14	17
(C1) H96/7257-46	105
(C1) H99/7649-42	120
(C1) H99/9779-4	172
(C1) H93/3710-16	66
(C1) H96/7156-14	102
(C1) H95/5713-145	83
(C1) H90/3068-50	63
(C1) H95/5734-31	84
(C1) H95/5763-19	88
(C1) H2001/2922-6	60
(C1) H93/3869-24	69
(C1) H95/5747-125	85
(C1) H95/5759-25	87
(C1) H95/4726-101	74
(C1) H87/33-02	38
(C1) H87/237-86	42
(C1) H97/7780-9	123
(C1) H89/1018-13	44
(C1) H90/3290-17	64
(C1) H98/8355-2	145
(C1) H93/3808-52	68
(C1) H95/4746-7	75
(C1) H95/5820-11a	91
(C1) H99/9737-22	169
(C1) H97/7784-30	141
(C1) H95/4453-22	70
(C1) H99/9756-16	171
(C1) H95/5184-1	82
(C1) H96/6234-2	95
(C1) H2001/2920-7	59
(C1) H96/5837-18	92



Appendix 7.11 (cont.): Cluster Analysis (Complete linkage) of all 177 steatite artifacts

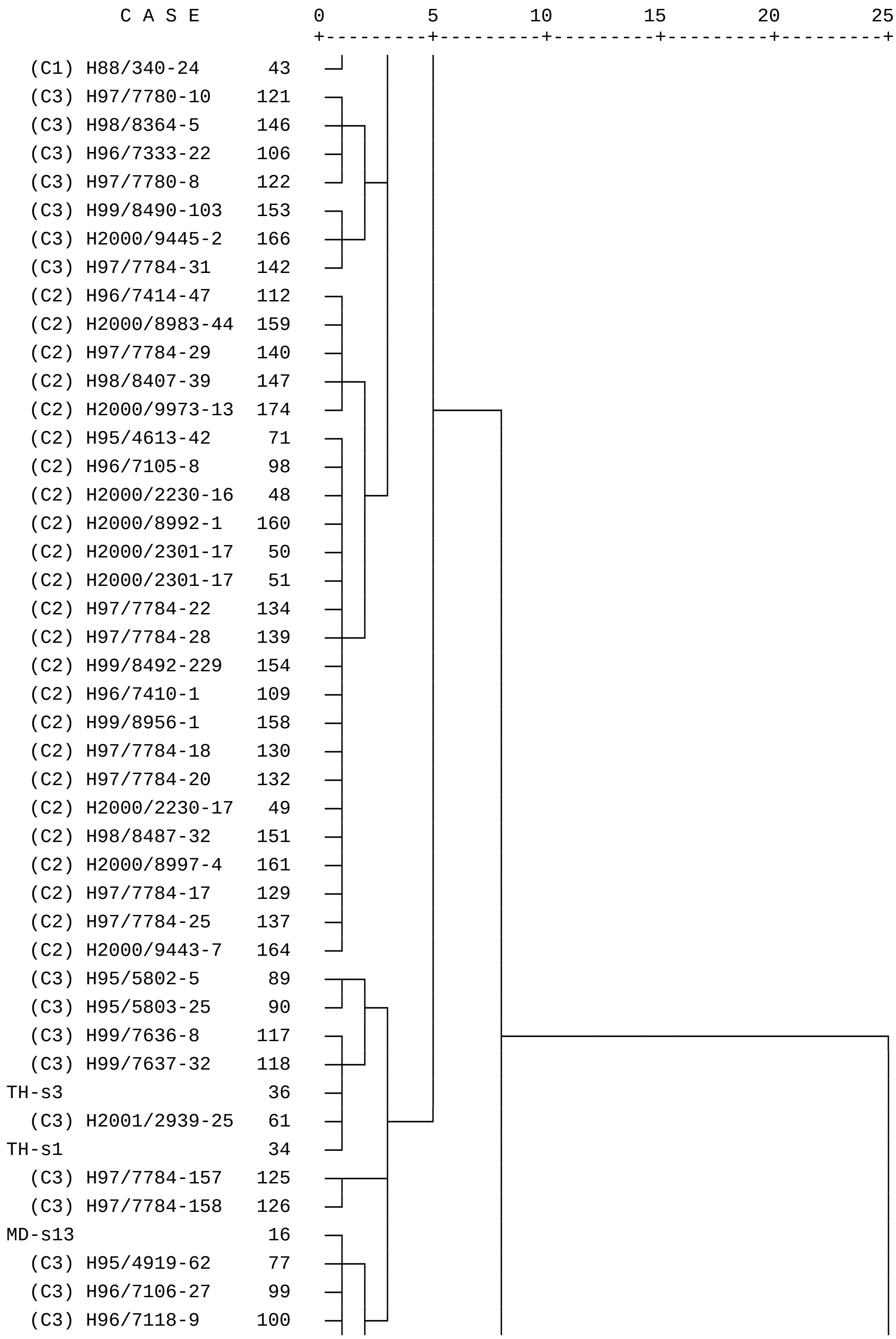
Section B



CASE	
(C1) H90/3030-55	62
(C1) H95/5749-97	86
(C1) H2001/2373-10	52
(C1) H96/6257-21	96
(C1) H97/7784-16	128
(C1) H2000/2230-14	46
(C1) H96/7410-2	110
(C1) H97/7784-23	135
(C1) H97/7619-3	116
(C1) H97/7784-21	133
(C1) H2000/2230-15	47
(C1) H94/5135-34	81
(C1) H98/8487-33	152
(C1) H2000/2880-16	57
(C1) H95/6509-97	97
(C1) H95/4751-8	76
(C1) H96/7467-790	114
TH-s5	37
(C1) H93/3534-13	65
(C1) H96/7358-11	107
(C1) H96/7153-14	101
(C1) H99/9747-33	170
(C1) H95/4615-94	72
(C1) H2001/2913-12	58
MD-s12	15
MD-s15	18
MD-s11	14
(C1) H96/7239-26	103
MD-s1	4
(C1) H2000/11001-6	175
(C1) H2001/11562-2	176
MD-s6	9
MD-s8	11
MD-s4	7
(C1) H96/7531-16	115
MD-s3	6
MD-s5	8
(C3) H99/7638-1	119
(C3) H99/7794-3	143
(C3) H87/86-229	40
(C3) H87/86-236	41
(C3) H87/86-228	39
(C3) H93/3710-70	67
(C3) H99/8760-77	157
MD-s10	13

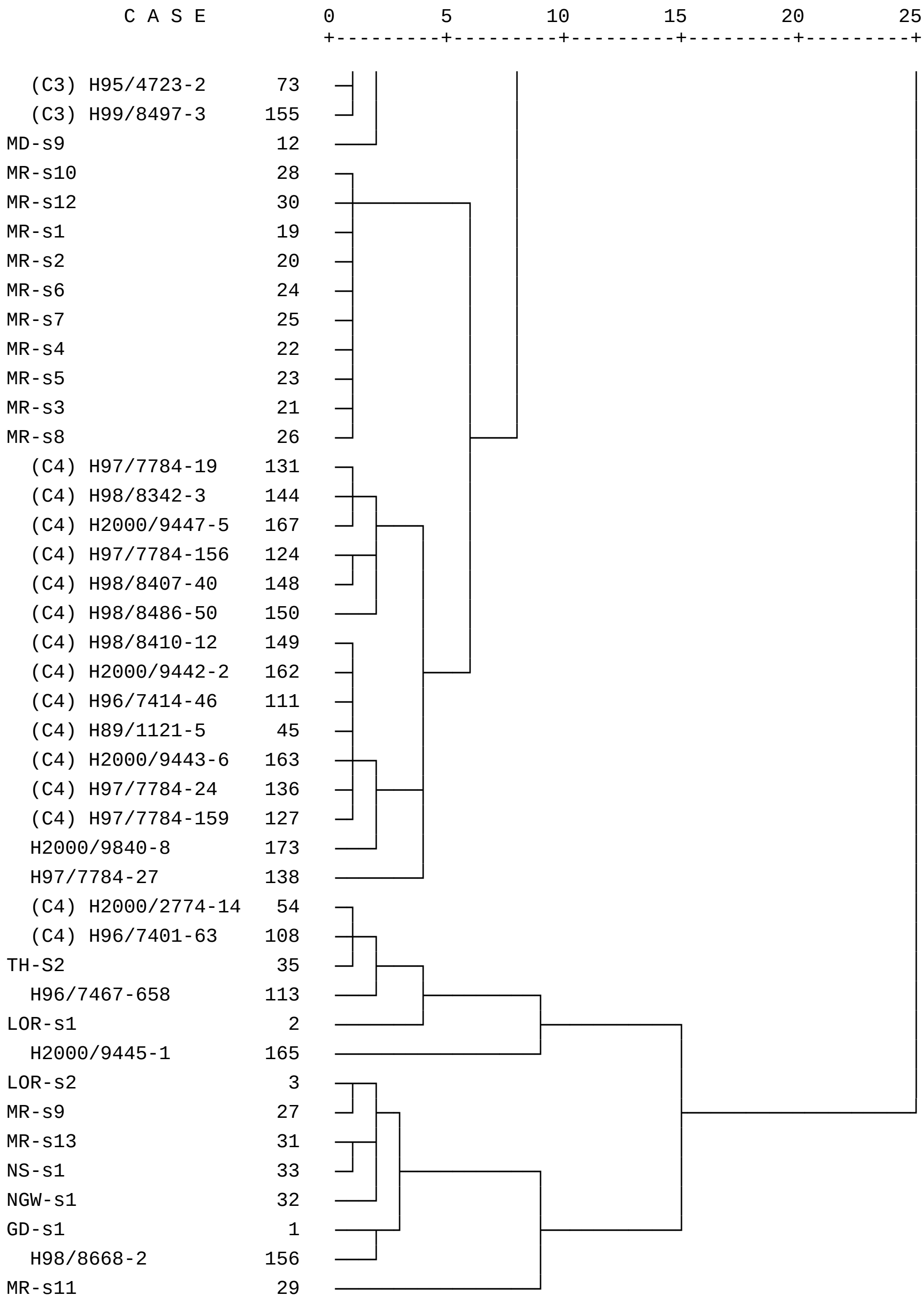
Appendix 7.11 (cont.): Cluster Analysis (Complete linkage) of all 177 steatite artifacts

Section C



Appendix 7.11 (cont.): Cluster Analysis (Complete linkage) of all 177 steatite artifacts

Section D



Appendix 7.12: Notes on experimental heating of black steatite from Mehrgarh

In May of 2004, Dr. Jean-François Jarrige and Catherine Jarrige kindly provided me with a small set of steatite artifacts from the site of Mehrgarh for use in geologic provenience analyses and experimental heating studies. Among the set were a number of jet-black bead roughouts and fragments that, along with several hundred other such artifacts, had been recovered from an MR4 atelier dating to the early Chalcolithic Period (Mehrgarh IIB – ca. 5000 BC) (Jarrige 1981: 99). Seven of the atelier artifacts were examined using INAA (Chapter 7 – Figure 7.7 B, MR-s1 through MR-s7) and determined to likely represent steatite from a single dolomitic deposit that is, perhaps, located in central Balochistan. It had already been established in previous studies conducted by Barthélémy de Saizieu and Bouquillon (1994, 1997) that this type of steatite became white when heated. As part my effort to understand the properties that made steatite from certain sources desirable to Indus craftspeople, I decided to further document the macroscopic and mineralogical changes that "Mehrgarh Black" steatite undergoes as it is heat-treated.

A large fragment of the "Mehrgarh Black" steatite (Appendix 7.12, Figure 1 *top*) was selected for the heating experiment. Although I did not know it at the time, the fragment had a calcite phase in addition to the main talc phase (XRD was not performed until after the initial firings were complete and I had not read Vidale's 1995 article in which he also documented this secondary phase). Had I known this, I would not have used that particular fragment as I was mainly interested in documenting the decomposition of talc into enstatite and cristobolite. Barthélémy de Saizieu and Bouquillon's XRD (1994: Figure 3.4) analysis of black steatite from Mehrgarh had indicated that it was entirely talc.

The fragment I chose was cut into 16 chips (Appendix 7.12, Figure 1 *bottom*). For the first round of firings, nine chips (**Set One**) were heated separately in a muffle furnace at different temperatures for exactly one hour each. The numbers 4 through 12, which correspond to the temperature that each was subjected to – 400ºC to 1200ºC in increments of 100ºC, were scratched on their surfaces. Length, width and thickness measurements were made for each chip in Set One before and after the firings (Appendix 7.12, Figure 2). This was a *static* firing in that each chip was placed into the furnace when the experimental temperature was reached and then removed immediately after the one hour. XRD was conducted on the unfired fragment and then on each fired chip (Appendix 7.12, Figure 3) to determine if and how its mineral composition had been altered by the heat to which it had been subjected. Based on the results provided by Set One, a second set (**Set Two**) of seven samples was static fired for three-hour periods at temperatures between 600ºC and 1200ºC.

XRD of the unfired "Mehrgarh Black" steatite sample

Both talc and calcite phases are evident in the raw sample. In their unfired state the steatite chips have a very dark gray appearance with a matte textured surface.

Observations SET ONE

MGR 400ºC @ 1 hr

Talc and calcite phases. The intensity of the major calcite peak has dropped slightly indicating that it is already beginning to decompose. The macroscopic appearance of the steatite remained unchanged.

MGR 500ºC @ 1 hr

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase remains practically unaltered. The appearance of the steatite remained unchanged.

MGR 600ºC @ 1 hr

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase is still largely unaltered. The appearance of the steatite remained unchanged.

MGR 700ºC @ 1 hr

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes. The talc phase is largely unaltered. The appearance of the steatite remained largely unchanged although a few light gray-white patches are evident.

MGR 800ºC @ 1 hr

Talc and calcite phases. The intensity of the major calcite peak continues to diminish as that mineral decomposes and several of the minor calcite peaks have disappear. The talc phase is beginning to show signs that that decomposition has begun. Much of the steatite chip is now mottled with gray-white patches.

MGR 900ºC @ 1 hr

Talc with minor calcite and enstatite phases. A single, much diminished calcite peak remains. Peaks indicating the formation of enstatite are now evident. The appearance of the steatite is now a cloudy gray-white with spots of pure white.

MGR 1000ºC @ 1 hr

Enstatite with a minor talc phase. The calcite has entirely decomposed. Most of the steatite has converted to enstatite leaving only a few minor peaks. The appearance of the steatite is now white with spots and streaks of gray-white.

MGR 1100ºC @ 1 hr

Enstatite with a minor talc phase. Enstatite is well formed while a few minor peaks for talc remain. The steatite is now almost entirely white.

MGR 1200ºC @ 1 hr

Enstatite with cristobolite and a minor talc phase. Mostly well-formed enstatite. A few minor peaks for talc remain and strong peaks for cristobolite are now present. The steatite is entirely white.

In the one hour static firings of this particular black steatite sample the conversion of talc to enstatite began somewhere between 800ºC and 900ºC (closer to the latter judging from the peak intensities). Enstatite was fully developed by 1100ºC. Cristobalite phases did not appear until temperatures approached 1200ºC. A more or less fully white color was not achieved until temperatures of around 1000ºC to 1100ºC were reached. Although the overall drop in weight (≈ -19%) and volume (≈ -14%) was fairly significant by 1200ºC, little deformation or cracking of the chips was evident.

Observations SET TWO

MGR 600ºC @ 3 hrs

Talc and calcite phases. The intensity of the major calcite peak is actually much stronger here than it was in the sample that had only been heated for one hour at 600ºC. A few light gray patches are evident on the chip.

MGR 700ºC @ 3 hrs

Talc and calcite phases. The intensity of the major calcite peak has diminished significantly as that mineral decomposes. The talc phase is largely unaltered from before. A few light gray-white patches are evident on the steatite chip.

MGR 800ºC @ 3 hrs

Talc and calcite phases. The calcite has almost entirely decomposed. Most of the steatite chip is now mottled with gray-white patches.

MGR 900ºC @ 3 hrs

Enstatite with talc. The calcite is entirely gone and the talc has undergone conversion to enstatite leaving only minor peaks behind. The appearance of the steatite is now a cloudy gray-white with spots of white

MGR 1000ºC @ 3 hrs

Enstatite. The remaining talc has entirely decomposed. The appearance of the steatite is now white with a few gray-white spots and streaks.

MGR 1100ºC @ 3 hrs

Enstatite with a minor cristobolite phase. The appearance of the steatite chip is now entirely white.

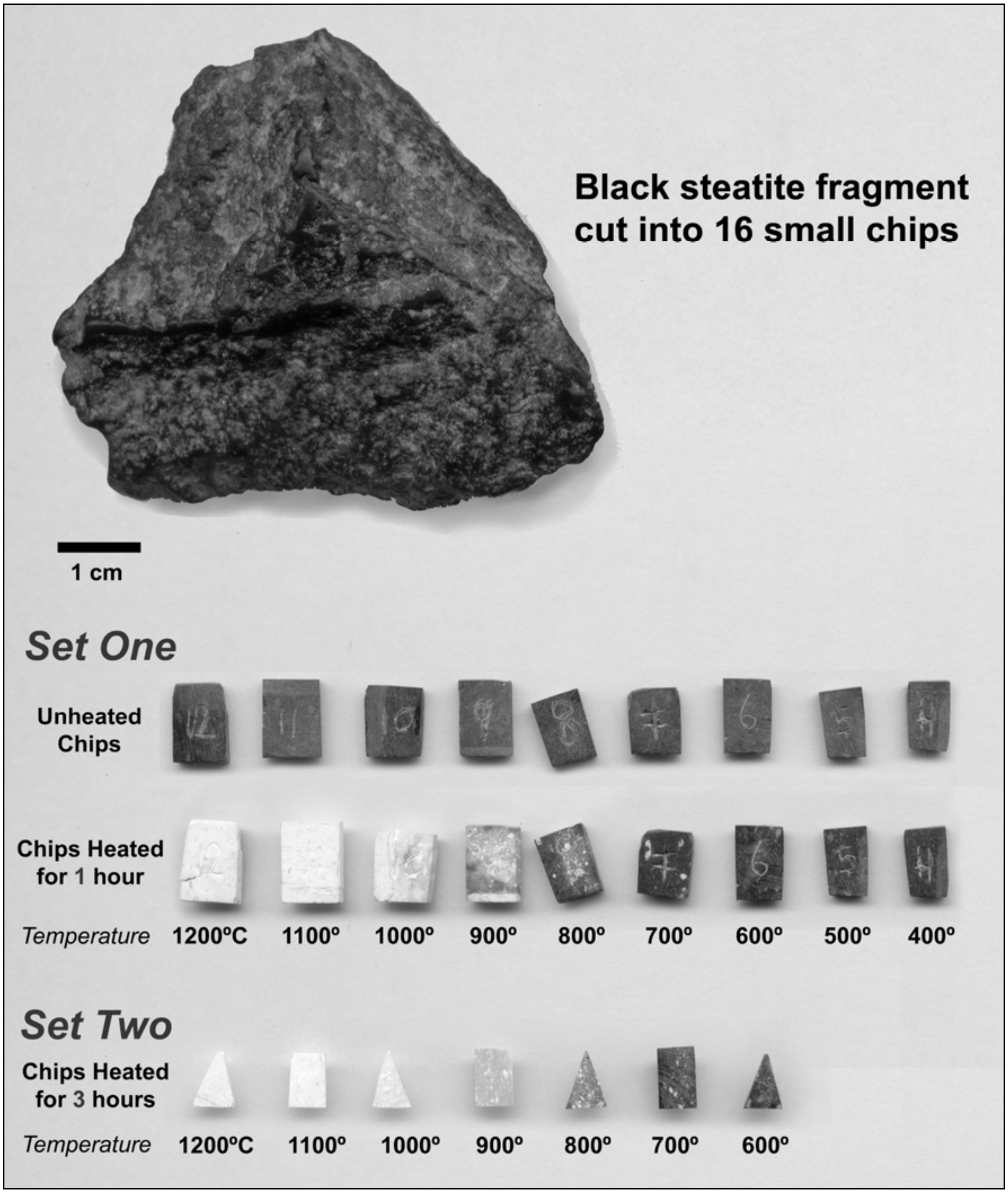
MGR 1200ºC @ 3 hrs

Enstatite and cristobolite phases. The macroscopic appearance of the steatite chip is now entirely white.

The XRD scans of Set Two indicate that, in general, longer firing times produce more developed and, in some cases, slightly earlier mineral phase changes. Enstatite still does not appear until around 900ºC but it shows better peak development. Talc entirely was completely gone by 1000ºC whereas it had never entirely decomposed in the 1-hour firings. Cristobolite now appears at 1100ºC and is well formed by 1200ºC. The appearance of the steatite still does not fully transform into a pure white color until around 1000ºC to 1100ºC.

Appendix 7.12, Figure 1:

Black steatite fragment from MR4 atelier used in this experimental heating study.

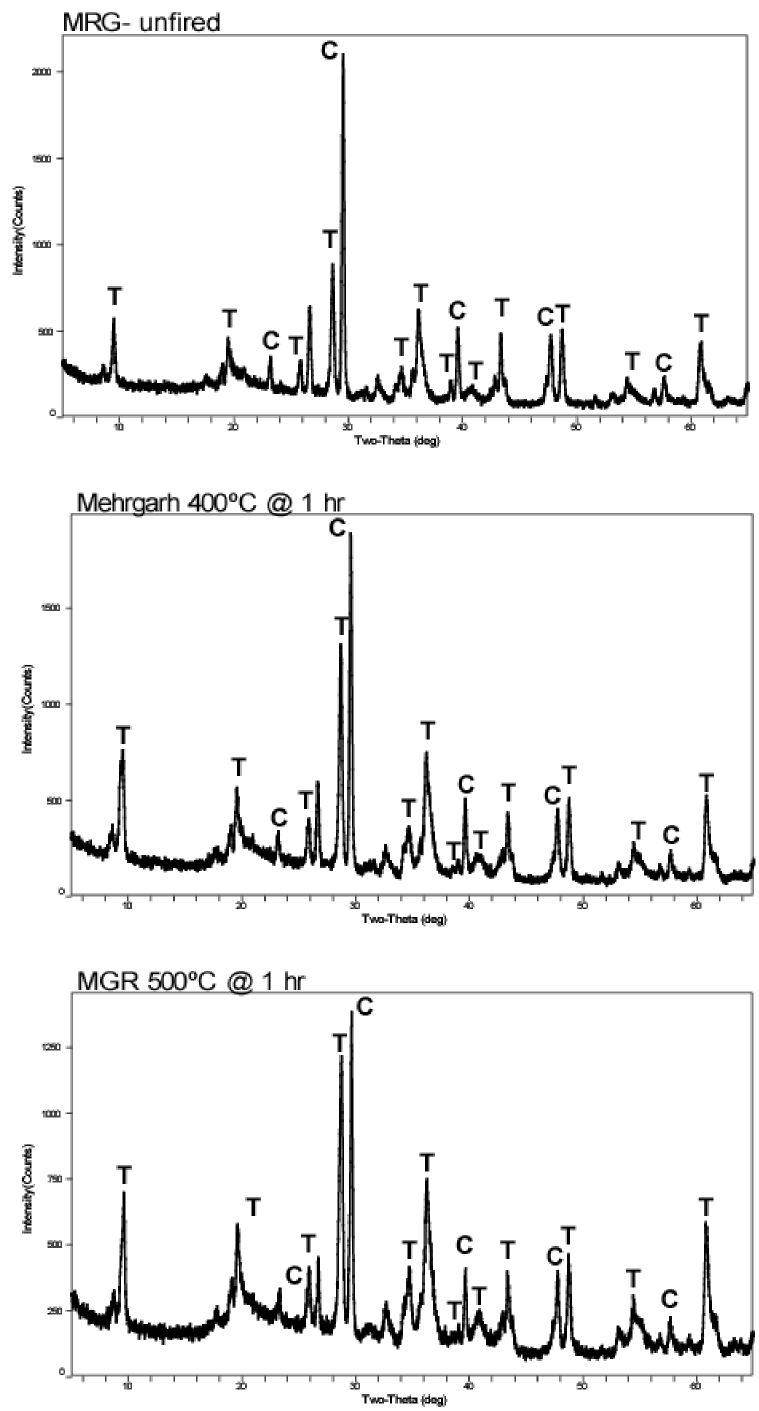


Appendix 7.12, Figure 2: Mehrgarh Black Steatite Heating Experiment – SET ONE

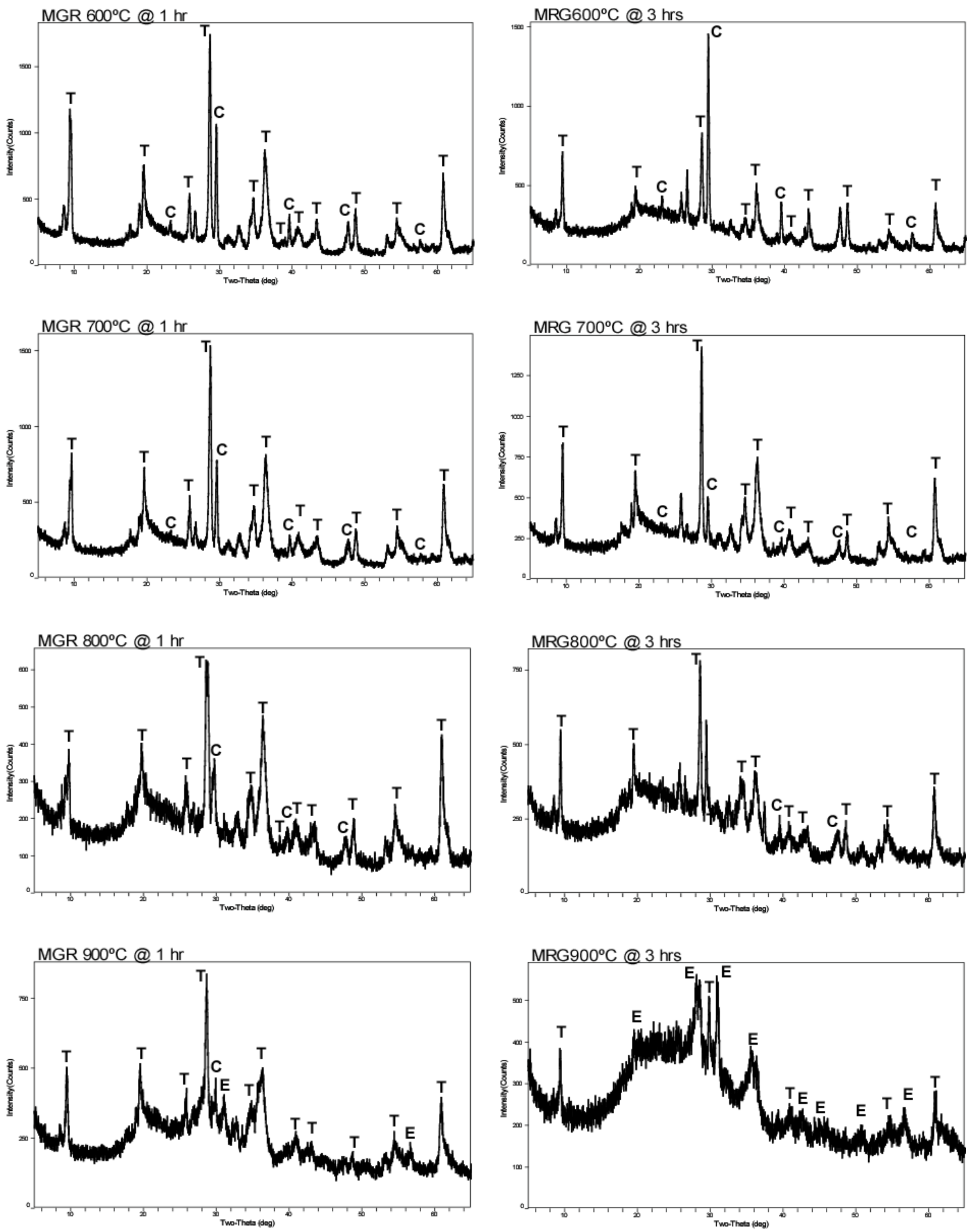
Before Heat-treatment									
STEATITE CHIP	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
LENGTH (mm)	8.5	8.29	9.18	8.24	8.6	9.29	8.69	9.6	9.76
WIDTH (mm)	5.13	5.11	5.87	6.45	5.86	6.32	7	7.09	6.4
THICKNESS (mm)	1.61	1.92	1.19	1.67	2.1	1.89	1.81	1.49	1.91
WEIGHT(g)	0.1502	0.1998	0.1571	0.2024	0.2595	0.2712	0.2543	0.2687	0.2998
After Heat-treatment									
TEMPERATURE	400°C	500°C	600°C	700°C	800°C	900°C	1000°C	1100°C	1200°C
LENGTH (mm)	8.48	8.26	9.17	8.15	8.57	9.35	8.76	10.01	10.05
WIDTH (mm)	5.1	5.1	5.87	6.51	5.87	6.38	7.15	7.26	6.74
THICKNESS (mm)	1.61	1.92	1.18	1.67	2.11	1.92	1.84	1.54	2.01
WEIGHT(g)	0.1495	0.1992	0.1563	0.1979	0.2482	0.2358	0.2071	0.2184	0.2431
Change									
VOLUME	-0.82%	-0.56%	-0.95%	-0.17%	0.30%	3.21%	4.67%	10.35%	14.12%
WEIGHT	-0.47%	-0.30%	-0.51%	-2.22%	-4.35%	-13.05%	-18.56%	-18.72%	-18.91%

Appendix 7.12, Figure 3: XRD scans of experimental steatite chips

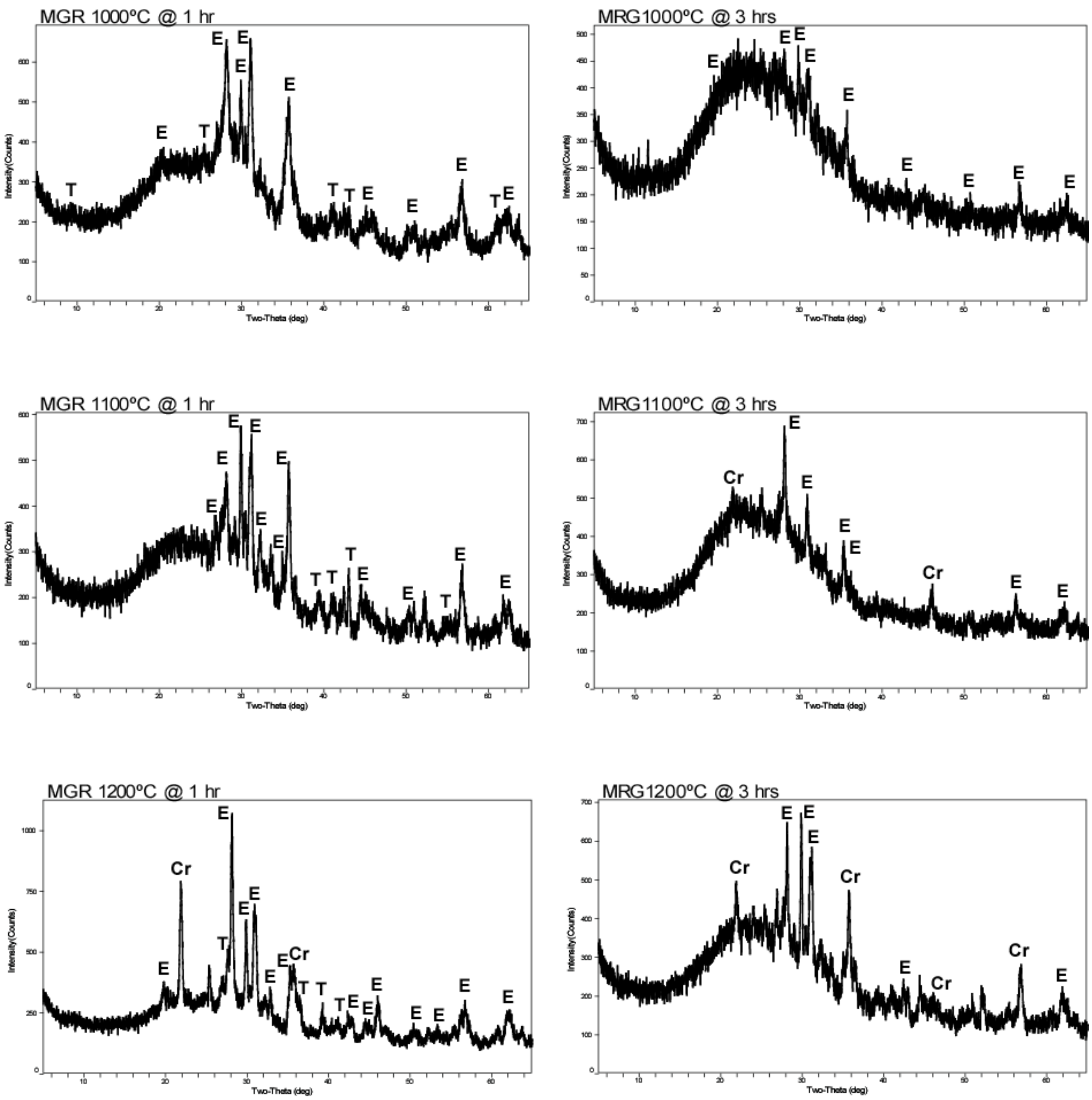
Peak Key: **T** = talc, **C** = calcite; **E** = enstatite, **Cr** = cristobolite



Appendix 7.12, Figure 3 (cont.): XRD scans of experimental chips



Appendix 7.12, Figure 3 (cont.): XRD scans of experimental chips



<u>Appendix 7.13</u><u>: XRD characterization of six white beads from Mehrgarh</u>

Along with the unfired steatite artifacts discussed in the previous appendix (7.12), Dr. Jean-François Jarrige and Catherine Jarrige also provided me with six tiny white beads from Mehrgarh periods I and II levels for characterization using XRD. The scans for these beads can be found on the next page (Appendix 7.13, Figure 1) along with a peak key.

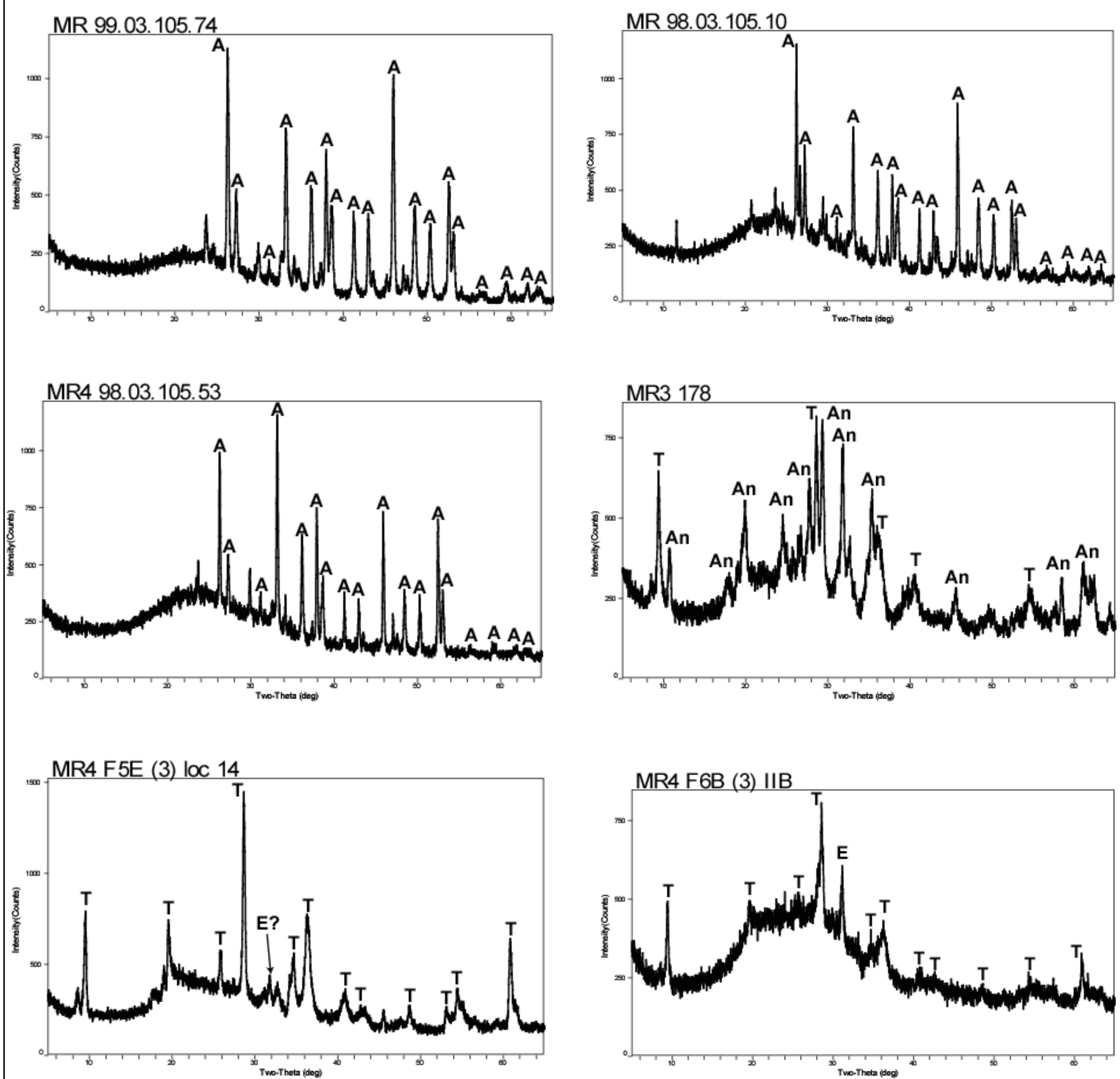
Three of the Period I beads (MR.99.03.74, MR.98.03.10 and MR.98.03.53) were determined to be composed of *aragonite* – a calcium carbonate similar to calcite. The XRD patterns of the remaining three revealed them to be made from talcose materials with characteristics consistent with those reported by Barthélémy de Saizieu and Bouquillon's in their study (1994) of Mehrgarh steatite beads from the same periods. Bead MR3 178 (from Period I) is composed mainly of *anthophyllite* with secondary phases of talc. Anthophyllite is an asbestos-like mineral that, because it occurs in both ultramafic igneous and dolomitic sedimentary rocks (Deer et al. 1992: 235), is not particularly helpful for determining the stone's geologic provenience. The nearest reported natural occurrence is in the Sakhakot-Qila ophiolite of the Mohmand Agency, FATA (Ahmed 1987b). The mineral could, however, be related to the thermal decomposition of talc to enstatite. In experimental heating studies of talc, Greenwood reported (1963) the formation and breakdown of an intermediate stage of anthophyllite between 667º ± 8ºC and 745º ± 10ºC.

Scans of the final two white beads (MR4 F5E (3) loc 15 and MR4 F6B (3) IIB), which are both from Period IIB, revealed talc peaks and a few minor enstatite peaks. After comparing those scans to the ones produced in the experimental heating study of the Mehrgarh black steatite fragment (Appendix 7.12), I would estimate that the beads were

fired at a temperature between 800 and 900ºC – probably closer to 900ºC given the presence but poorly developed appearance of the enstatite peaks. That temperature is consistent with Barthélémy de Saizieu and Bouquillon's previous estimate (1994: 51) for fired steatite beads of this period.

Appendix 7.13 Figure 1: XRD scans of six white steatite beads from Mehrgarh

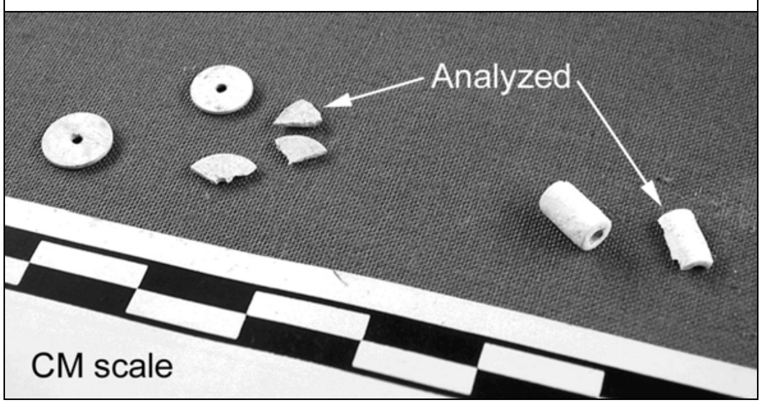
Peak Key: **T** = talc, **E** = enstatite, **A** = Aragonite, **An** = Anthophyllite



Appendix 7.14: XRD characterization of steatite beads from Harappa and Loralai

The thermal decomposition of talc into enstatite and cristobolite can provide an indication of how high of a temperature was achieved during the firing of a steatite artifact. Here firing temperatures of two prehistoric steatite beads are assessed using XRD. For the first analysis, one of three pieces of a broken disc bead (Appendix 7.14, Figure 1 *left*) was chosen from a bag of miscellaneous surface finds from Mound E at Harappa (H94/4999). A second XRD analysis was conducted on a broken tubular bead provided by Syed Ghani of the Geological Survey of Pakistan-Quetta. It is said to be from a mound in the Loralai District, Balochistan (Appendix 7.14, Figure 1 *right*).

Appendix 7.14 Figure 1:
Disc beads and disc bead fragments from Harappa (left)
Tubular bead and tubular bead fragment from Loralai (right)

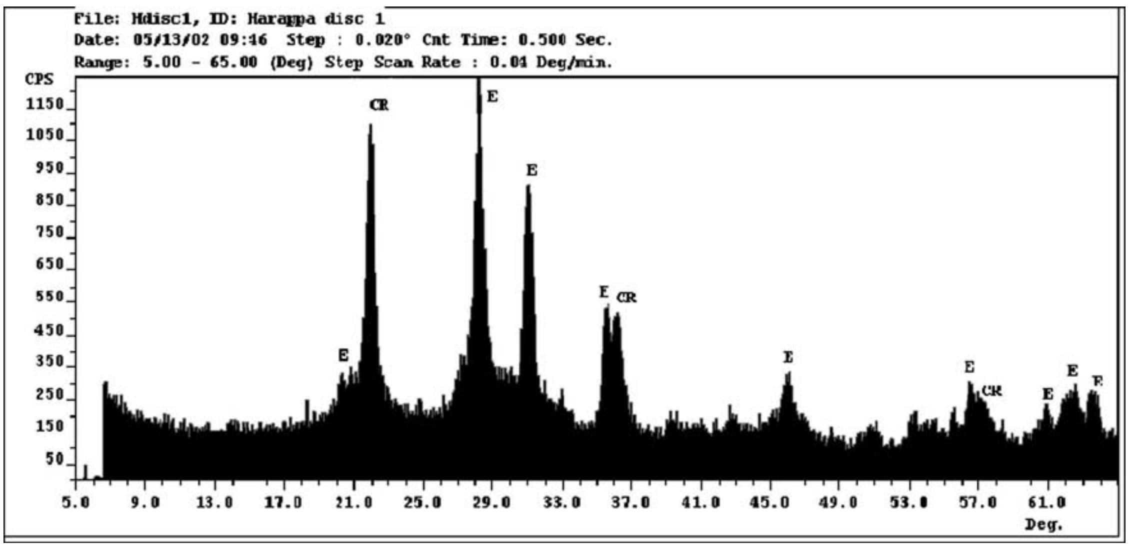


The XRD scan of the disc bead fragment from Harappa (Appendix 7.14, Figure 2) indicates that it is composed of enstatite (E) and cristobolite (CR). The cristobolite is very well developed suggesting that a firing temperature of close to 1200ºC was probably achieved (compared the scan of the disc bead to that for experimental sample from Mehrgarh [Appendix 7.12, Figure 3] that was fired for 1 hour at 1200ºC). The scan of the Loralai tubular bead fragment (Appendix 7.14, Figure 3) shows that it is also composed of enstatite and cristobolite. However, the cristobalite is not as well-developed as it is in the disc bead from Harappa. This probably indicates that a firing temperature of only around

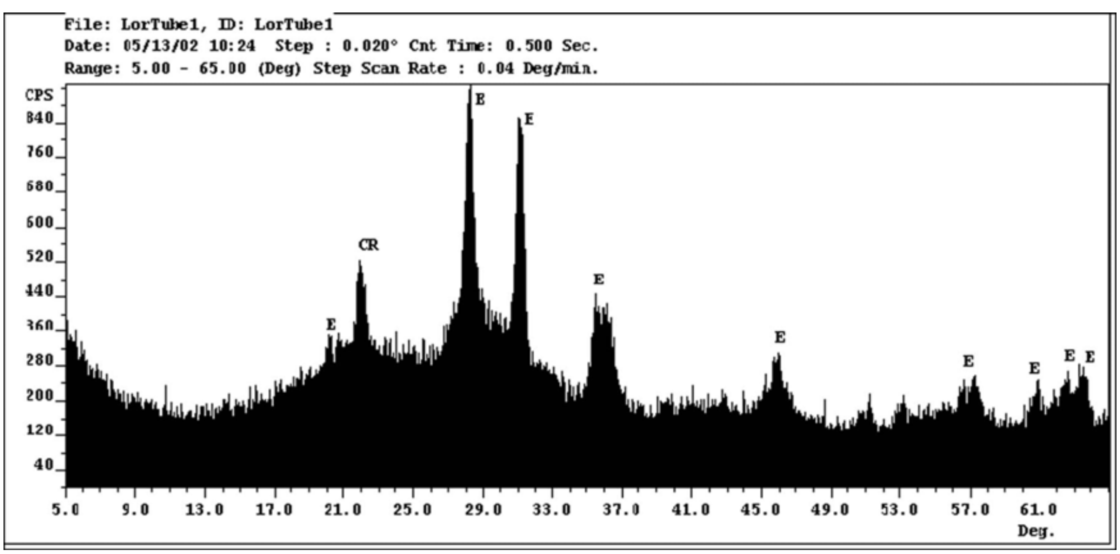
1100ºC was reached (compared the scan for the bead to that for Mehrgarh sample [Appendix 7.12, Figure 3] that was fired for 3 hours at 1100ºC).

Peak Key:
T = talc, **Cr** = cristobalite, **E** = enstatite

Appendix 7.14, Figure 2: XRD scan of a disc bead fragment (H94-4999-601) from Harappa



Appendix 7.14, Figure 3: XRD scan of a tubular bead fragment from the Loralai Valley



Appendix 7.15: EMPA observations of a steatite seal boss from Harappa

I show in Appendix 7.16 that certain types of steatite will fire to a bright, pure white color without any kind of treatment whatsoever. However, most Harappan steatite stamp seals evidently have been modified so as to provide them with an enamel-like white exterior. The exact nature of that modification has long been the subject of debate (Miller 1999: 309). Some researchers have proposed that a glaze was applied to these objects (Mackay 1931d; Sana Ullah 1931) while others have argued that they were subjected to a type of surface treatment using an alkaline solution (Beck 1934; Kenoyer 1998; Vidale 2000). In this appendix, I present a few observations made during an electron microprobe analysis (EMPA) of a seal fragment. Although this cursory study does not definitively establish how seal surfaces were created, in my opinion, it does lend some support to the view that these objects may be covered with a thin talcose glaze.

Artifact H90/3208-68 (Appendix 7.15 Figure 1 A and C) is a portion of a steatite seal *boss* (the perforated knob that is found on the reverse sides of seals). In antiquity, it broke from the seal that is was a part of (see Appendix 7.15 Figure 1 B for a reconstruction) and was subsequently recovered in Period 3C levels in Trench 59 on the south side of Mound E at Harappa. The exterior surface of the boss is white and is rife with fine cracks that are reminiscent of a glaze that has undergone crazing. In places this "glaze" (if indeed that is what it is) has fallen away to reveal the off-white fired steatite subsurface beneath it. The yellowish unfired or "raw" steatite that the seal was carved from is visible on the broken reverse side of the boss. Heat-treatment has altered the steatite from the surface to a depth of between one and four millimeters. A rough fractured

area as the base of the boss is the remains of a substantial crack (labeled in Appendix 7.15 Figure 1 C) in the body of the seal. It clearly existed during the manufacture of this object as it exhibits the same "glaze" and/or treatment as the surface of the seal. This crack is probably is the reason (or part of the reason) why the boss broke from the seal body. That could have happened during manufacture or the crack may have weakened the boss causing it to snap off later.

In his study of seals from Mohenjo-daro, the Archaeological Survey of India's chemist K.B.M. Sana Ullah concluded (1931: 688) that the exterior of those artifacts was coated with a talcose slip. An analysis of the surface layer of one (ibid.: 689, Table 1 #8) indicated that it was primarily composed of magnesium silicate with only a trace amount (1.8%) of water. This layer is almost certainly talc that has thermally decomposed to enstatite. Sana Ullah proposed that the slip was made from powdered steatite that has been previously fired (this was already enstatite). A trace amount alumina and ferric oxide (2.4% total) was also detected in the surface layer. This may indicate that a minute quantity of iron-rich clay was added to the talcose slip, perhaps as a binder. However, in his experimental attempts to replicate the white surface, Sana Ullah instead added "silicate of soda" (Sodium silicate – Na_2SiO_3) to powdered fired steatite. He found that this method produced "durable coatings, similar to the ones on the seals" (ibid.: 688).

Based on thin-section studies of Harappan seals, Horace Beck concluded (1934: 80-81) that "the surface had not been added as a paste, but that the seals had been carved completely from a block of steatite, and then treated with an alkali and heated." Both Kenoyer (1998: 73) and Vidale (2000: 62) concur that, rather than being covered by an

applied slip/glaze, the seals were subjected to some type of alkaline mixture – perhaps calcium carbonate ($CaCO_3$ or "free lime") and potassium hydroxide, (KOH or "potash"), prior to firing. A slip, it is argued (Mark Kenoyer *personal communication*), would obscure the finely carved details and minute manufacturing marks that are plainly visible on surfaces of seals. Soaking them in an alkaline solution and then applying heat would essentially "bleach" the surface leaving any details/marks intact.

In order to evaluate the two different explanations for the white exterior of Harappan seals – i.e, glaze vs. surface treatment, an exploratory EMPA of the seal boss described above was conducted. A small piece that is actually a remnant of the flat reverse side of seal rather than of the boss itself was sawn from the artifact (red lines on Appendix 7.15 Figure 1 A & B indicate the portion that was removed). This piece (≈ 7 mm in width) was prepared according to the methods outlined in the EMPA section of Chapter 2. The section left by its removal is displayed and labeled in Appendix 7.15 Figure 1 C. A thin white layer is plainly visible on the seal surface portion of the section as well as along the contours of the crack on its left hand side. The contrast between the heated portion of the seal body and its unaltered steatite interior is likewise evident in the section.

Appendix 7.15 Figures 2 A and B are two back scattered electron (BSE) images of the prepared seal sample. In Figure 2 A, a surface layer approximately 35 microns (0.035 millimeter) thick stands in contrast to the homogenous fired steatite of the seal's immediate subsurface interior. Figure 2 B is a BSE image detail of that layer. Three sub-layers are visible (labeled on the figure as 1, 2 and 3) each of which is approximately ten microns or so in width. The seal body immediately beneath the surface layers is labeled "4" and a

point around 100 microns in depth is labeled "5" on the figure. At each of the five points I performed a scan using the probe's energy dispersive spectrometer (EDS), which provided fast, qualitative chemical characterizations. The composition of the material at each point was exclusively magnesium silicate. There were no peaks observable peaks in the EDS spectrum that would indicate the presence of potassium, calcium, sodium, aluminum (indicative of clay minerals), lead or any other substance that might conceivably have been added or applied as a binder, flux or colorant. Based on this, it was decided on not to calibrate the probe with mineral standards (a time consuming process) and conduct quantitative assays using its wavelength dispersive spectrometer (WDS).

Compositionally, the seal's surface layer is identical to its fired interior. This could then be seen as support for Mackay's assertion (1931d: 379) "that the coating upon these seals is made of the same material as the seals themselves," that is, talc/enstatite. On the other hand, if the seal's original carved steatite surface was bleached using an alkali treatment and then heated, its basic mineralogical composition (magnesium silicate) might not have been altered very much or even at all. The EDS assessments, therefore, cannot really provide an answer to the glaze vs. treatment question.

The BSE images are more revealing. Looking at Appendix 7.15 Figures 2 B, we see that although the platy interlocking grains of the seal's interior lighten (darken on the BSE image) as layer 3 begins, the texture remains homogenous through layer 3 up to layer 2. After that point the texture suddenly becomes much courser. It seems to me that if there is an applied surface it probably begins this sharp layer 2 to 3 boundary. Layer 3 may then be the original carved surface of the seal that has undergone some form of alteration due to its

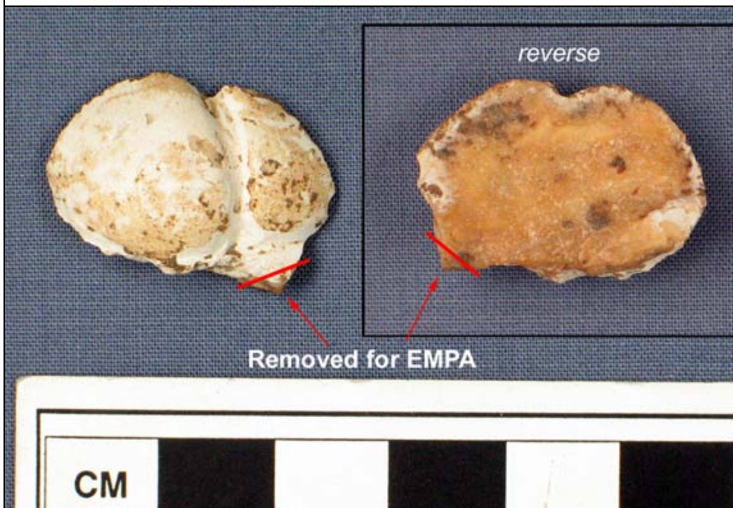
fusion with the glaze. Note that the indicated micro-crack runs from the surface through layer 3. As the glaze scales off it will take some of the original carved surface with it.

What of that original carved surface of the seal? Would not a slip obscure details and manufacturing marks? It would if a "wet glaze" (Miller 1999: 308) that was too thick and viscous was applied to a seal. However, it is possible to produce extremely fine and fluid steatite slips (Grosjean 1999). If layer marked "3" is assumed to be the original seal surface then the remaining "glaze" is only around 20 microns (0.02 millimeter) in thickness. A slip that thin could have adhered to the contours of carved details and manufacturing marks and still left them visible. It also probably could have worked its way into and coated the crack that is evident in the seal body (labeled on Appendix 7.15 Figure 1 C), something that Beck argued (1934: 81) an applied paste would not have done.

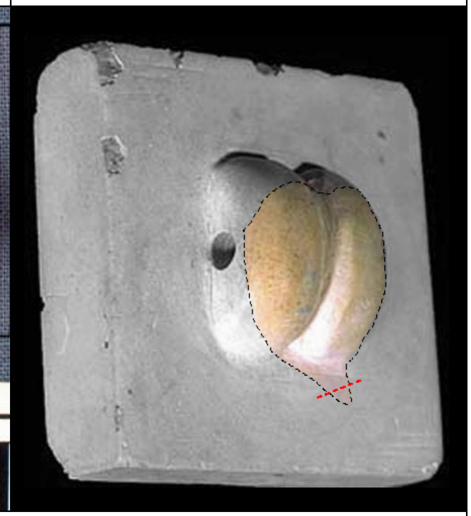
In the end, the observations made in this appendix are equivocal. Considerable more research and, especially, experimentation will have to be conducted in order to satisfactorily demonstrate how the white coating on Harappan steatite seals was created. However, at this point I am inclined to think that it was an applied talcose glaze rather than an alkaline surface treatment – at least for the seal fragment that was examined here. It is possible, perhaps even likely, that both techniques were used to white seals (either separately or in combination with one another).

Appendix 7.15, Figure 1: Broken steatite seal boss – H90/3208-68

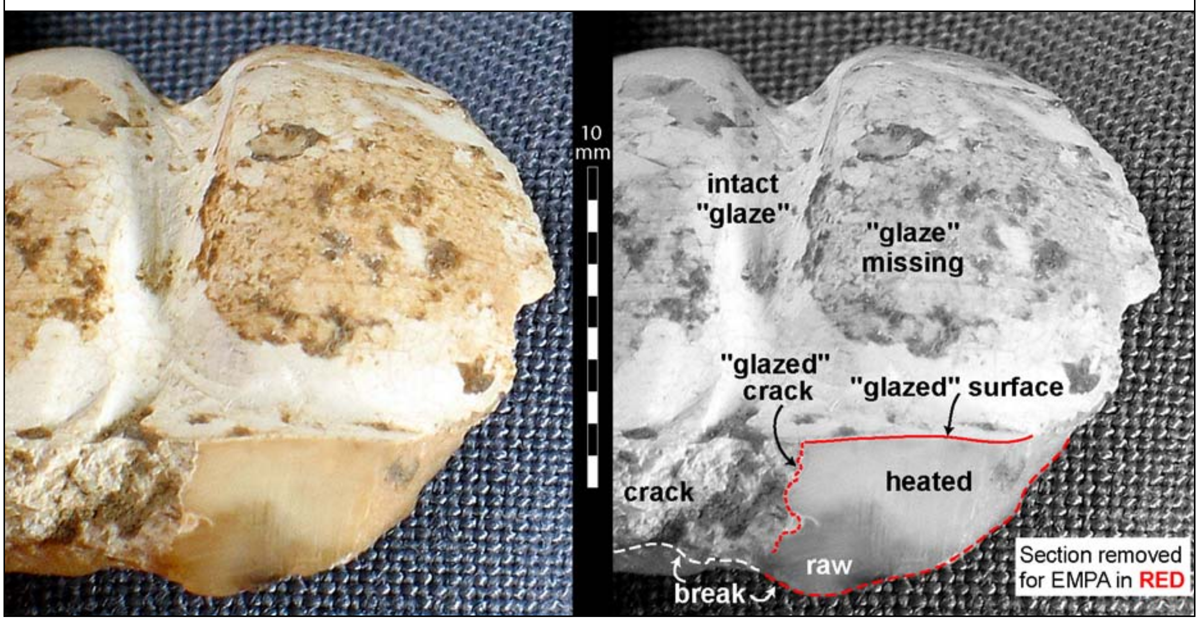
A: “Glazed” exterior (left) and unfired or “raw” steatite interior (right).



B: Reconstruction

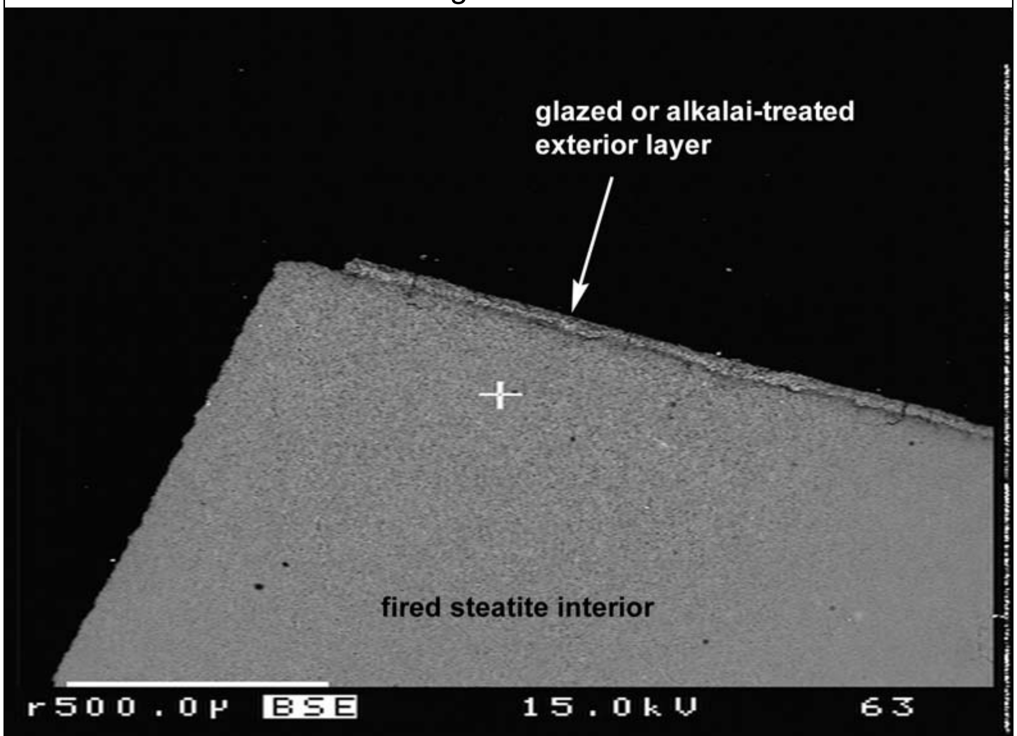


C: Steatite seal boss / interior section (left) and boss / section labeled (right).

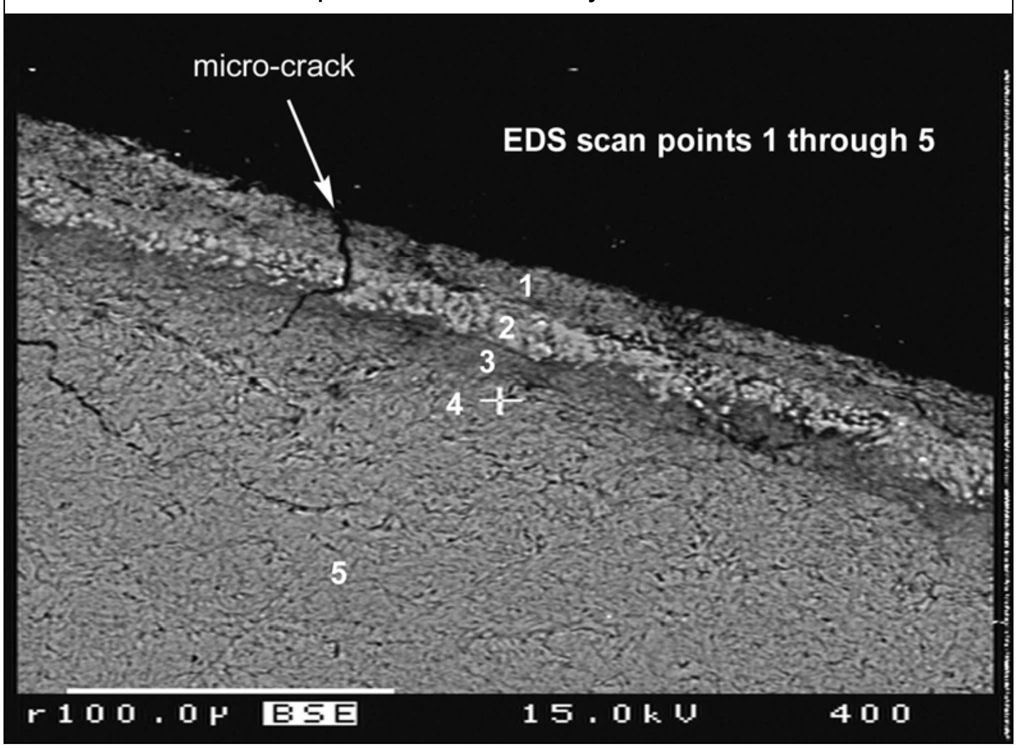


Appendix 7.15 Figure 2: EMPA of steatite seal boss

A: BSE image of boss section



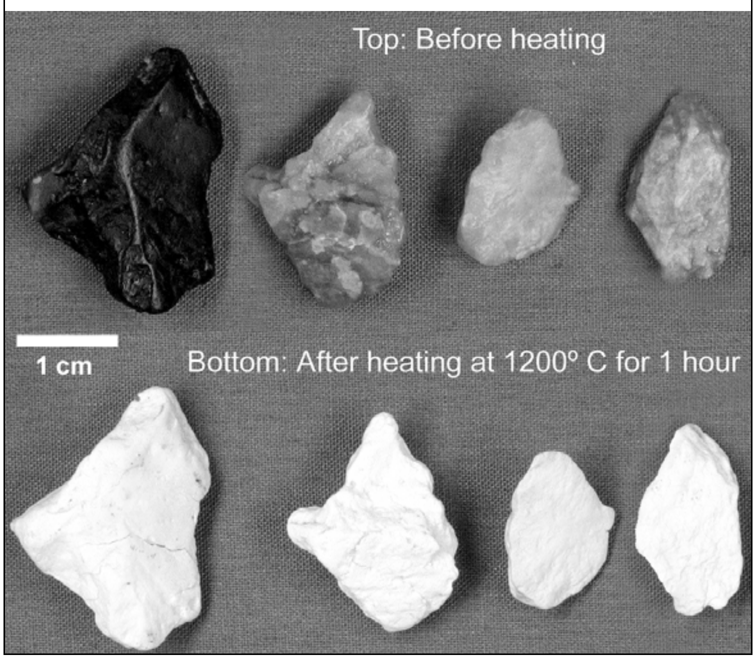
B: EDS scan points of exterior layer and seal interior



Appendix 7.16: Heating and characterization of steatite from various geologic sources

Barthélémy de Saizieu and Bouquillon (1994: 51) heated "raw steatite flakes found at Mehrgarh" and observed that their color turned from black to white between 800ºC to 900ºC. I heat-treated four steatite fragments (unworked and unprovenienced pieces turned in by a workman) from Harappa that were of varying colors including jet black (Appendix 7.16, Figure 1). After a one hour static firing at 1200º C, all four had become bright white, just like the tens of thousand of heat-treated steatite artifacts recovered at the site. That the color of these unfired scraps of raw steatite left behind by Indus Tradition craftspeople should transform in this way is not at all surprising as a white appearance was what was evidently sought when objects made from this variety of stone were fired (see p. 416). The debris from manufacturing such objects should naturally become white also. However, can we conclude that all steatite fires white? In this appendix, I provide an overview of my attempts to answer this question. In addition, I detail the effort to characterize the quality/workability of steatite from different geologic sources in Pakistan and India.

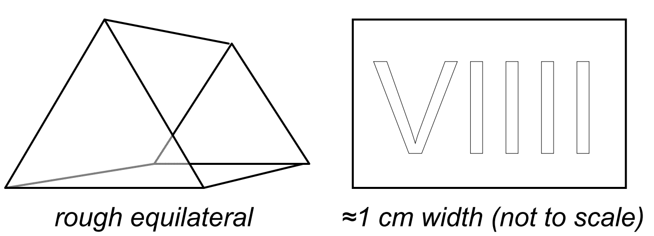
Appendix 7.16 Figure 1: Experimental heating for four unworked steatite fragments from Harappa (surface finds)



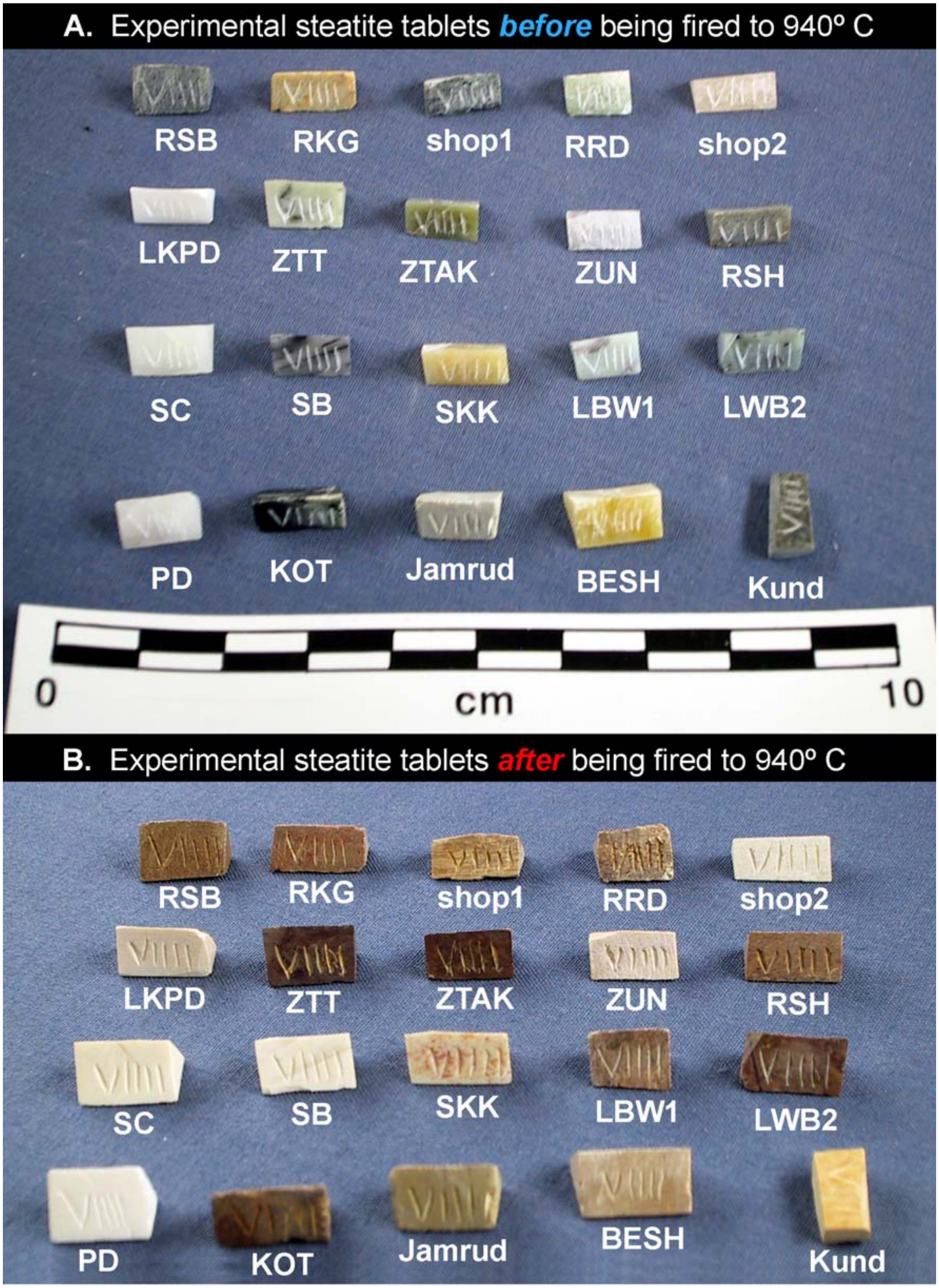
My initial steatite heating and characterization experiments were conducted in the Spring of 2002. At that time, samples from only 20 locations were available for study (these are listed in Appendix 7.16, Figure 4). Sixteen were from steatite sources that would go on to be included in the geologic dataset (their source codes correspond to those used in Chapter 7 and listed in Appendix 7.2). Two others were from sources in Pakistan – Jamrud in the Khyber Agency, FATA and Kund from the Peshawar District, NWFP (see pp. 321-323). Neither of these would be analyzed for the provenience study due, in large part, to the observations reported in this appendix. The final two samples were taken from steatite purchased in shops. Sample "shop 1" was obtained from the workshop of a steatite carver named Ravi Soni in Udaipur, Rajasthan. Sample "shop 2" was purchased from the main bazaar in Attock City, northern Punjab Province, Pakistan.

In order to gauge the quality/workability of the stone from each of the different sources, the blanks to be heat-treated were fashioned into replicas of prism-shaped incised steatite tablets in dimensions (Appendix 7.16, Figure 2) approximating those reported in Meadow and Kenoyer (2000). The tablets were carved using a replica of a Harappan period bronze saw that was reconstructed by Dr. J. Mark Kenoyer based on scanning electron microscopy (SEM) studies of steatite debitage (Kenoyer 1997b). The Harappan sign "VIIII" was incised onto one face of each of the tablets using a copper stylus with a beveled end. The 20 completed, unfired replicas can be seen in Appendix 7.16, Figure 3 A.

Appendix 7.16, Figure 2: Experimental tablet dimensions



Appendix 7.16, Figure 3: Heating experiment using steatite from 20 locations.



As is evident on Appendix 7.16, Figure 3 A, not all of the experimental tablets could be carved into prism-like shapes with nice even edges. While some of the problem had to do, no doubt, with my lack of skill as a carver, much of the difficulty was attributable the stones themselves. The heavily foliated steatite from Kund kept splitting. Ultimately the tablet from that source had to be made flat and rectangular. The Jamrud steatite had a great deal of quartz in it that made sawing difficult. It was shaped only after considerable effort. Problematic inclusions were encountered in the KOT and "shop 1" samples. Most of the remaining tablets were fairly easily carved and incised, however.

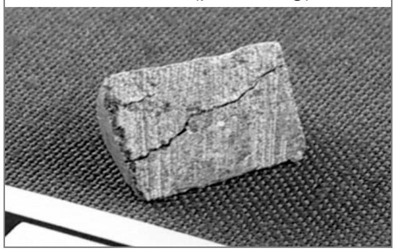
Prior to firing, each tablet was weighed, measured and its color characterized using a Munsell Rock Color Chart. The surfaces of all of them could be scratched using a calcite crystal and thus each had a hardness of 2½ or less on the Mohs' Mineral Hardness Scale (Appendix 2.1). They were then placed in a muffle furnace and the temperature was slowly raised 60°C per hour to 940° C. The tablets were held at this temperature for one hour and then the furnace was turned off and allowed to cool slowly overnight. The next day all were re-weighed, measured and color-characterized. The post-firing hardness of the tablets was scratch-tested using apatite (hardness 5), feldspar (hardness 6), quartz (hardness 7).

The post-firing appearance of the incised tablets is pictured in Appendix 7.16, Figure 3 B (the before and after Munsell characterizations are listed in columns three and four of Appendix 7.16, Figure 4). Only five of them (PD, SC, SB, LKPD, ZUN and "shop 2") exhibited a post-firing color that was white (or anything close to it). It is important to note that all but one (SB) of those was white or near-white in appearance to begin with. The color of most of the remaining tablets had become a dull rusty red.

Appendix 7.16 Figure 4: Descriptions of the 20 geologic steatite samples used in the initial heating experiment.

Source	*Parent-Rock*	*Pre-fire color*	*fired color*	*volume change*	*weight change*	*final hardness*
PD	Dolomite	Very light gray N 8	White N 9	9.00%	-1.48%	6
KOT	Ultramafic	Greenish black 5 G 2/1 to Greenish gray 10 GY 5/2	Dark yellowish brown 10 YR 4/2	-5.00%	-3.20%	5 to 6
Jamrud	Dolomite	Very light gray N 8	Pale yellowish brown 10 YR 6/2	1.75%	-1.44%	5
BESH	Dolomite	Yellowish gray 5 Y 8/1	Yellowish gray 5 Y 8/1	-4.00%	-0.76%	5 to 6
Kund	Dolomite	Dark greenish gray 5 GY 4/1	Grayish orange 10 YR 7/4	n/a	n/a	5 to 6
SC	Dolomite	Very light gray N 8	Very light gray N 8	-0.75%	-2.28%	6
SB	Dolomite	Med. Light gray N 6 to Dark gray N 3	White N 9	-0.75%	-1.49%	6
SKK	Dolomite	Yellowish gray 5 Y 8/1	Yellowish gray 5 Y 8/1	-2.00%	-2.32%	6
LBW1	Ultramafic	Very pale green 10 G 8/2 to Med. Dark gray N 4	Dark yellowish brown 10 YR 4/2	-2.75%	-2.03%	5 to 6
LBW2	Ultramafic	Greenish gray 5 G 6/1 to Black N 1	Dark yellowish brown 10 YR 4/2	-0.75%	-2.60%	6
LKPD	Dolomite	White N 9	Pinkish gray 5 YR 8/1	-3.75%	-1.56%	5 to 6
ZTT	Ultramafic	Light greenish gray 5 G 6/1 to Grayish black N 2	Dusky yellowish brown 10 YR 2/2	-13.50%	-2.07%	6
ZTAK	Ultramafic	Dusky yellow green 5 GY 5/2	Dusky yellowish brown 10 YR 2/2	2.00%	-1.85%	6
ZUN	Ultramafic	Med. Light gray N 6	Yellowish gray 5 Y 8/1	0.25%	-1.38%	6
RSH	Ultramafic	Dusky yellow green 5 GY 5/2 to 5 GY 3/2	Dark yellowish brown 10 YR 4/2	-2.00%	-2.33%	5 to 6
RSB	Ultramafic	Dark greenish gray 5 GY 4/1	Dark yellowish brown 10 YR 4/2	-12.00%	-3.89%	5 to 6
RKG	Ultramafic	Grayish orange 10 YR 7/4 to Dark yellowish orange 10 YR 6/6	Dark yellowish brown 10 YR 4/2	-11.00%	-2.12%	5 to 6
Shop1	unknown	Pale green 5 G 7/2	Grayish orange pink 5 YR 7/2	3.00%	-3.25%	6
RRD	Ultramafic	Dark greenish gray 5 GY 4/1 to Greenish black 5 GY 2/1	Grayish orange pink 5 YR 7/2	9.00%	-2.46%	5 to 6
Shop2	unknown	Grayish orange pink 5 YR 7/2	Pinkish gray 5 YR 8/1	3.75%	-0.47%	5 to 6

Appendix 7.16, Figure 5
Tablet RRD (post-firing)



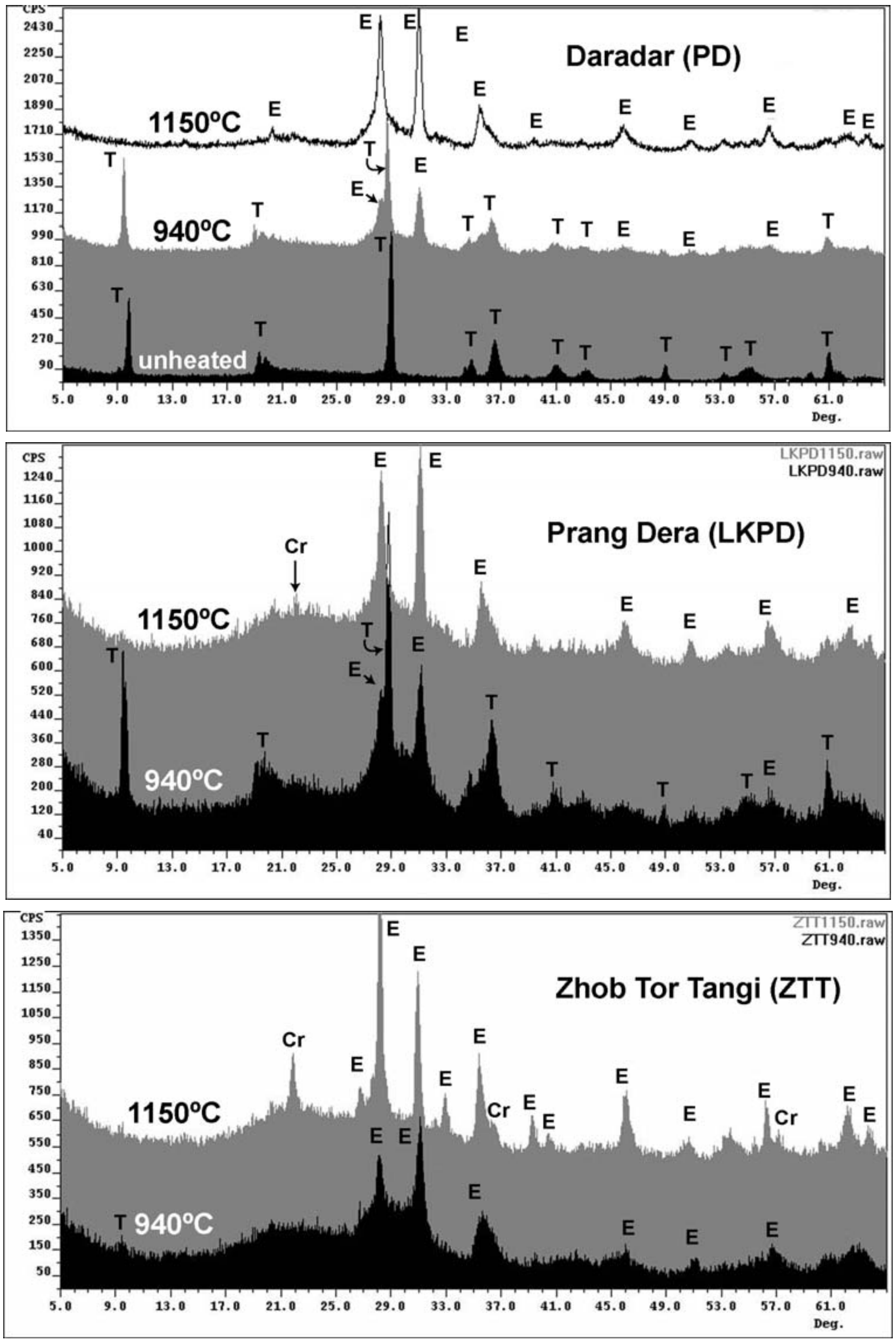
Post-firing changes in volume, weight and hardness for each tablet are listed in the fourth through sixth columns of Appendix 7.16, Figure 4. Most of them held up well physically, meaning that heat-induced changes in weight and volume (due to water being driven off during the conversion of talc to enstatite) did not cause them to split, crack or flake. Only the tablet carved using steatite from RRD (from Rishab-der in southern Rajasthan) exhibited any significant cracking (Appendix 7.16, Figure 5). Mineral scratch tests indicated that the Mohs hardness for most tablets was just around 6 while some fell between 5 and 6.

A series of XRD analyses were performed on select tablets – from PD, LKPD and ZTT. Each of these was sawn into two pieces, one of which was re-heated to 1150ºC for one hour. No further macroscopic changes were evident after the halves were reheated (i.e, they did not become any whiter) but their hardness increased to between 6 and 7 (PD and LKPD) to 7 (ZTT). Unheated powder from the carving of tablet PD was also X-rayed.

Composites of all XRD scans for the three tablets can be seen in Appendix 7.16, Figure 6. In each one, talc had begun to transform into enstatite by 940ºC, although the decomposition/formation of those minerals was different from tablet to tablet. In ZTT, talc had all but disappeared (there is a minor peak at around 9.75º) while in LKPD it was still the dominant mineral. Talc had entirely decomposed in each of the tablet halves that were heated to 1150ºC. Cristobalite had begun to form in ZTT and, just barely, in LKPD. No cristobalite peaks were evident in the scan for PD, however. The varying Mohs hardness values in the heated samples are attributable to the differential formation of these minerals.

Appendix 7.16, Figure 6: XRD scans of heated steatite samples from three sources

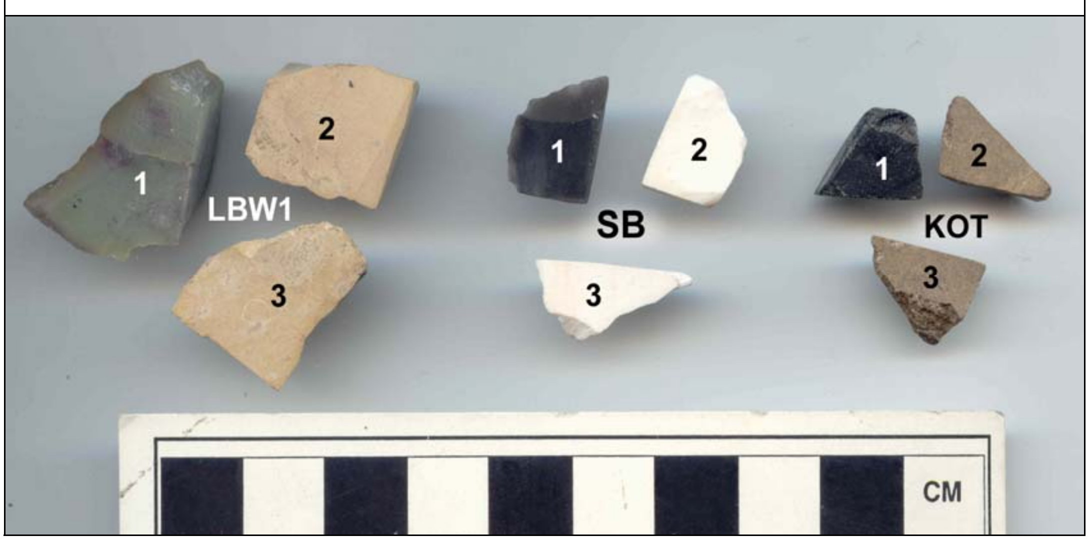
Peak Key: **T** = talc, **Cr** = cristobalite, **E** = enstatite



The results of the initial heating experiment indicated several things. First and most importantly, it was quite clear that not all steatite becomes white when it is heat-treated. It was also apparent that mineral composition, inclusions, foliation and bonding of raw steatite were all things that affected the ease to which steatite was carved and, probably, how well it held together when fired. Lastly, the hardness of fired steatite is a function of the temperature to which it was heated (and to a lesser extent how long it was heated). The formation of enstatite will impart a steatite object with a hardness of around 5 to 6. Only those tablets that were re-heated to 1150ºC exhibit a hardness of higher than 6.

Ernest Mackay documented (1933) the ancient process for bleaching white designs onto carnelian beads that involved heat in combination with an alkali-based solution. Upon seeing the results of the initial steatite heating experiment, Dr. J. Mark Kenoyer suggested that I attempt to bleach that stone using the same technique. I agreed to try. Raw steatite from three sources – LBW1, SB and KOT, were cut into three pieces each. These can be seen in the figure below (Appendix 7.16, Figure 7). The pieces labeled "1" are the raw,

Appendix 7.16, Figure 7: Experimental steatite heating in combination with bleaching.



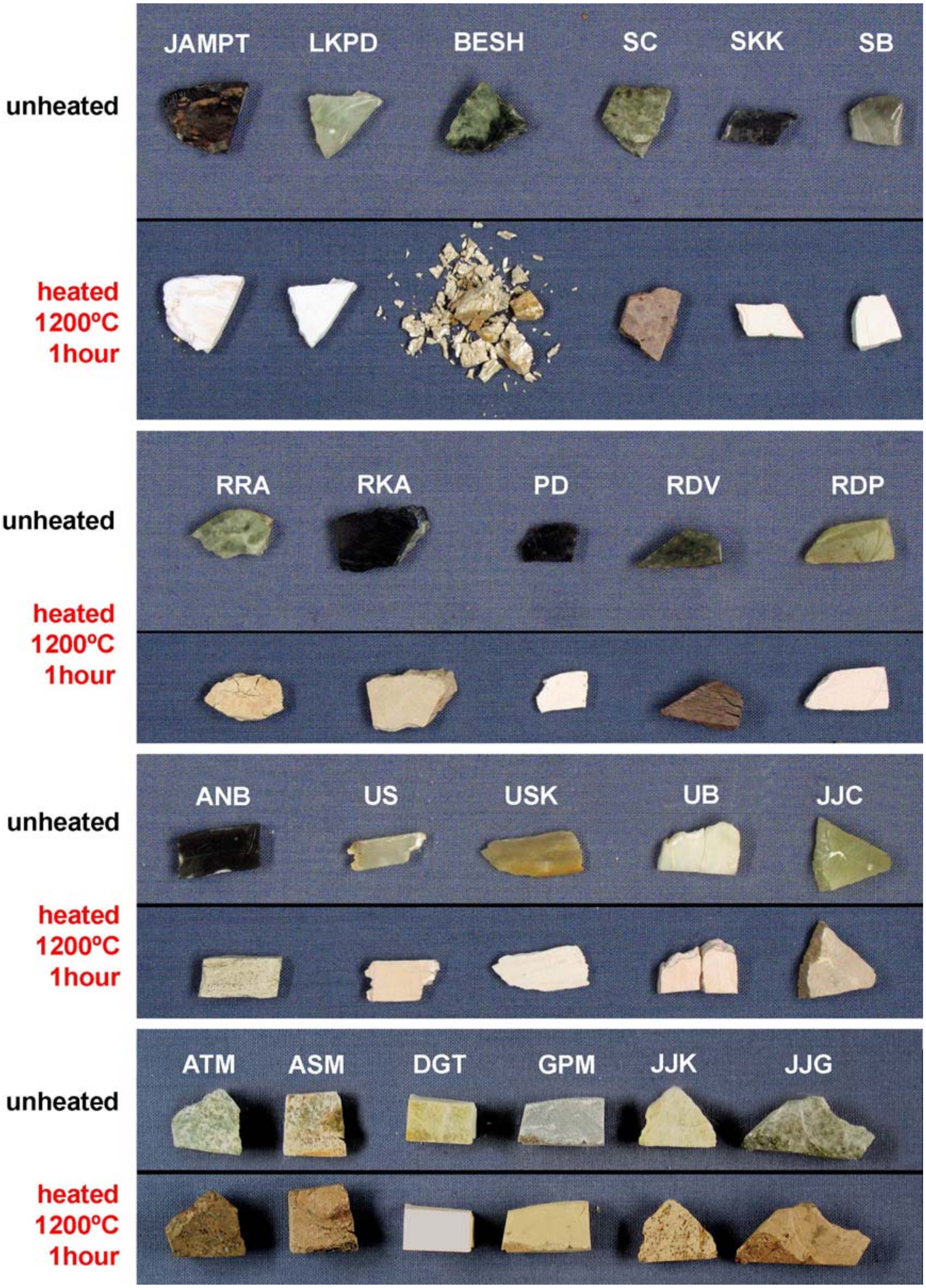
unfired stones. Those labeled "2" were treated with the carnelian bleaching solution recorded by Mackay. This consisted of sodium carbonate (Na_2CO_3) and juice from the "kikar" plant (*Capparis aphylla* – a type of caper native to South Asia) that was carefully mixed and strained. The steatite pieces were allow to soak in this solution for five days after which they were placed (while the exterior was still damp) into the muffle furnace. The temperature was slowly raised 60°C per hour to 1150° C, allowed to dwell there for one hour and then turned off to cool overnight. The pieces on the figure labeled "3" were soaked for five days in a paste of consisting of calcium carbonate ($CaCO_3$ – which Massimo Vidale [2000: 62] has previously suggested might have been used to whiten steatite) and potassium hydroxide (KOH) or "potash," which was added on the suggestion of Dr. Kenoyer. These were heated along with those soaked in the Na_2CO_3-kikar solution.

The photograph for Appendix 7.16, Figure 7 was taken after the bleaching/heating experiment was completed. Compare the pieces labeled "2" and "3" on that figure to the post-fired appearance of their corresponding tablets pictured in Appendix 7.16, Figure 3 B. Those from LBW1 and KOT exhibit exactly the same dull red post-fired appearance that they did in the initial heating experiment. The piece from source SB did fire white this time but it also fired white in the initial experiment in which it was untreated. There is nothing to indicate that the two alkali solutions affected any color change in the samples at all. Of course, this does not prove that Indus Tradition craftspeople were incapable of bleaching steatite. I may have incorrectly prepared and/or applied the solutions. However, new data began to come light around the time these experiments were conducted that suggested there was probably no need for Harappans to bleach steatite white.

The results of the provenience study of steatite that are detailed in Chapter 7 indicated that, of the 139 artifacts analyzed from Harappa (I exclude the BMAC wig), 138 appear to have been derived from sources of dolomitic origin (see Figure 7.14 on p. 341). An emphasis on the use of this type of raw material was seen at several of the other Indus Tradition sites from which steatite artifacts were analyzed. Furthermore, the majority of the dolomitic steatite artifacts from Harappa and Mohenjo-daro appear to have been derived from a select few deposits in northern Pakistan and India. Of those, samples from PD, LKPD, SB, SC and SKK were heat-treated in the initial experiment (Appendix 7.16, Figure 3). The post-firing appearance of all of them, save for the tablet made from SKK steatite, was white. None of the tablets from ultramafic sources had become that color except for the one from ZUN. That one was white to begin with and was actually became an off-white shade it was fired. So it seemed as if Harappans were very deliberately exploiting white-firing stone from dolomitic while ignoring non-white-firing ultramafic stone. However, except for the stone from SB, all of the white-firing dolomitic samples were also white to begin with. Raw steatite of that color has never been found at Harappa.

It was decided to heat a series of dolomitic steatite samples that, in appearance, were more like the raw material recovered at Harappa, that is – colorful (recall Figure 7.4). At the time I did this (Fall 2003), samples from 22 dolomitic sources had been obtained. Unfired chips taken from these are pictured in Appendix 7.16, Figure 8 in the rows marked "unheated." These chips were placed in the muffle furnace and the temperature was raised quickly (200°C per hour) to 1200° C and left to dwell for one hour. This time and temperature was sufficient to turn any kind steatite white if it was predisposed to do so.

Appendix 7.16, Figure 8: Heat-treated steatite chips from select dolomitic sources.



Post-firing images of the steatite chips are visible in the rows directly beneath the "unheated" ones in Appendix 7.16, Figure 8. The majority of them did not become white after being fired. Most of those that did are from sources in northern Pakistan and India (JAMPT. LKPD, SKK, SB and PD) that were predicted in Chapter 7 to have been ones used by residents of Harappa. Three chips from sources in Uttaranchal and Rajasthan also became white (USK and DGT) or near white (RDP). Although it was not my intent to the examine quality/workability of steatite from different sources, most seem to have held up well in this quicker and hotter firing. Three chips (RRA, RDV and UB) showed signs of cracking and one from BESH exhibited what can only be described as catastrophic failure.

A few important observations can be made as a result of this firing. Firstly, just as it is not possible to say that all steatite fires white it is also not possible to say that all dolomitic steatite fires white. Materials from some sources clearly will not. Moreover, there are good indications that even within individual steatite deposits there are raw materials that fire in different ways. Note that the SC chip did not become white in this last heating experiment but the SC tablet from the initial one did. The JAMPT chip fired bright white in Appendix 7.16, Figure 8 but recent (May 2007) studies by Gregg Jamison (a graduate student at the University of Wisconsin-Madison) using material from that source only produced light grayish-colored results. These observations actually fit well with my suggestion (discussed on pp. 364-367) that highly compositionally similar groups within the set of steatite artifacts analyzed from Harappa might represent raw materials extracted from a very restricted area *within* an individual occurrence. In order to obtain white-firing stone for their beads and seals, Harappans had to be (and clearly were) highly selective.

Appendix 8.1: INAA data for agate samples from Ratanpur, Gujarat. Data in parts per million (PPM)										
sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
GRTP-01	1850	0.5172	10.935	0.0799	2902	0.0812	174	0.3827	0.0517	2.120
GRTP-02	3401	0.7281	11.944	0.1589	2997	0.6739	187	1.1616	0.8657	13.430
GRTP-03	2971	0.6626	9.104	0.1173	2532	0.2722	313	0.7013	0.3903	6.644
GRTP-04	2645	0.3994	8.081	0.1026	2190	0.1150	350	0.6715	0.4669	6.210
GRTP-05	2235	0.3284	3.402	0.0729	974	0.0065	243	0.3304	0.0499	1.331
GRTP-06	1501	0.5769	6.972	0.0948	1996	0.1841	142	0.4123	0.2103	3.300
GRTP-07	1896	0.3891	5.328	0.0503	1210	0.0638	100	0.4977	0.0725	1.537
GRTP-08	3378	0.9297	15.977	0.1438	4353	0.7066	202	0.2559	0.8286	9.192
GRTP-09	1924	0.3305	4.592	0.0670	1234	0.0896	200	0.5290	0.0272	1.557
GRTP-10	2113	0.4627	3.878	0.0707	1913	0.1130	189	0.4690	0.1628	3.037
GRTP-11	1852	0.4095	5.724	0.0827	1531	0.1084	202	0.5406	0.0257	1.654
GRTP-12	2250	0.6177	6.852	0.0838	2306	0.0639	177	0.2773	0.5736	4.328
GRTP-13	1984	0.2480	0.679	0.0428	317	0.1130	197	0.4413	0.0126	1.304
GRTP-14	1747	0.1183	0.954	0.0401	139	0.0130	49	0.2171	1.5517	0.916
GRTP-15	2070	0.3017	11.942	0.0548	1052	0.0867	127	0.2432	0.0948	3.092
GRTP-16	2301	0.3953	0.804	0.0441	375	0.0555	263	0.5963	0.4464	1.082
GRTP-17	2559	0.3455	0.938	0.0466	604	0.1011	323	0.2978	0.2451	2.875
GRTP-18	2692	0.8421	12.279	0.0618	5875	0.1650	162	0.1217	0.8560	23.252
GRTP-19	2637	0.3066	0.906	0.0353	124	0.0384	469	0.1710	0.2384	0.827
GRTP-20	1962	0.2064	3.774	0.0262	490	0.0788	99	0.0821	0.1758	1.101

Appendix 8.2: INAA data for agate samples from Mardak Bet, Gujarat. Data in parts per million (PPM)

sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
GMB-01	1868	0.4005	3.560	0.0829	860	0.2008	337	0.1445	0.6170	1.208
GMB-02	1906	0.3403	6.861	0.0571	1664	0.0868	351	0.3705	0.0597	2.009
GMB-03	1960	0.3792	4.576	0.0815	1194	0.1086	404	0.2321	0.0265	1.614
GMB-04	2287	0.3765	2.704	0.0976	543	0.5745	392	0.1494	6.4109	0.833
GMB-05	1992	0.5975	7.095	0.0802	1788	0.1391	528	0.4998	0.8002	2.258
GMB-06	2014	0.3433	5.507	0.0495	1677	0.2123	379	0.1427	6.9568	0.958
GMB-07	2101	0.3493	4.339	0.1207	1048	0.5624	441	0.1298	0.0698	0.965
GMB-08	2052	0.6978	4.663	0.0733	957	0.2293	507	0.3478	4.6780	0.927
GMB-09	2291	0.7152	10.936	0.0919	2501	0.2803	575	0.1863	0.4679	3.368
GMB-10	2010	0.4439	5.695	0.0453	1267	0.2117	370	0.6212	5.3070	1.276
GMB-11	2058	0.4207	5.094	0.0754	1321	0.1195	331	0.6476	0.1010	2.742
GMB-12	1917	0.4063	8.021	0.0700	1712	0.0060	319	0.3900	0.0638	2.297
GMB-13	2305	0.1207	1.476	0.0534	213	0.9033	570	0.6653	4.9204	1.319
GMB-14	1946	0.1867	1.240	0.0376	260	0.1170	434	1.4944	3.7008	0.060
GMB-15	3426	0.4849	1.762	0.0250	2626	0.1205	572	0.0496	0.5073	9.910
GMB-16	6360	1.4611	3.647	0.0790	3597	0.5723	1551	0.2252	1.3634	14.253
GMB-17	3806	0.6573	1.805	0.0374	7683	0.3522	879	0.0040	0.3110	15.854
GMB-18	7844	1.4600	12.873	1.4685	4735	11.3524	1787	0.1413	3.9293	40.162
GMB-19	2394	0.2484	2.945	0.0400	822	0.3356	477	0.1104	3.9260	1.390
GMB-20	2567	0.1867	3.117	0.0178	773	0.0688	629	0.2699	0.1194	1.344

Appendix 8.3: INAA data for agate samples from Khandek, Gujarat. Data in parts per million (PPM)										
sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
GKK-01	1907	0.1946	0.284	0.0175	99	0.0065	165	0.1555	0.0296	0.934
GKK-02	1828	0.6039	0.833	0.0623	418	0.7129	78	0.0306	0.1315	0.942
GKK-03	3295	1.9164	6.802	0.1652	1590	0.8768	373	0.8363	0.4134	6.583
GKK-04	1747	0.4720	0.771	0.0269	236	0.0078	100	0.8305	0.0217	1.026
GKK-05	2324	0.4518	0.778	0.0313	365	0.0079	337	1.0483	0.0514	1.155
GKK-06	1955	0.4812	0.732	0.0550	489	0.3148	167	0.1913	0.0914	0.998
GKK-07	1910	0.7033	1.625	0.0799	595	0.4479	209	0.6103	0.0670	1.029
GKK-08	1766	0.2286	1.010	0.0227	149	0.1082	90	0.1865	0.0146	0.915
GKK-09	1985	0.2501	0.667	0.0284	223	0.0099	184	0.2774	0.0390	0.771
GKK-10	2520	0.7402	0.979	0.0336	1043	0.1650	304	0.1318	0.3259	2.624
GKK-11	2293	0.5263	0.818	0.0290	636	0.2094	334	0.2622	0.0990	1.943
GKK-12	3317	0.5683	1.032	0.0252	1048	0.2047	641	0.0836	0.4024	3.307
GKK-13	3482	0.4799	0.625	0.0814	974	0.7775	659	0.0988	0.1929	2.105
GKK-14	2322	0.1029	0.270	0.0241	90	0.0930	363	1.1208	0.0074	0.060
GKK-15	2351	0.2027	0.475	0.0530	300	0.6555	325	0.2968	0.0473	1.057
GKK-16	1963	0.1583	0.245	0.0173	138	0.0563	200	0.4982	0.0162	1.010
GKK-17	2900	0.7813	1.032	0.0485	988	0.3550	271	0.0588	0.2051	6.838
GKK-18	2064	0.8594	1.745	0.0231	1080	0.3374	301	0.1531	0.1952	4.384
GKK-19	2727	0.4311	0.677	0.0329	647	0.1992	348	0.6055	0.1841	3.354
GKK-20	2338	0.4700	1.029	0.0256	907	0.2174	335	0.3701	0.0860	2.293

Appendix 8.4: INAA data for agate artifacts from Shahr-i-Sokhta, Iran. Data in parts per million (PPM)

sample	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
S-i-S_01	2409	0.5995	5.404	0.0718	5013	0.6939	632	3.4254	0.2027	0.754
S-i-S_02	2005	0.5482	7.577	0.0712	2099	1.9471	475	2.9873	0.1325	2.097
S-i-S_03	2159	0.3412	5.310	0.0736	1367	0.4809	469	3.0094	0.0965	1.482
S-i-S_04	3799	0.3242	7.035	0.0793	2584	2.6748	1172	2.9185	0.3235	1.169
S-i-S_05	1761	0.3868	5.303	0.0471	2263	0.2711	415	1.8996	0.0801	0.908
S-i-S_06	1834	0.5544	7.959	0.0785	2666	3.1115	602	4.1397	0.1636	2.304
S-i-S_07	2015	0.3247	4.248	0.0430	1753	0.5431	574	2.6235	0.1795	1.828
S-i-S_08	1692	0.3087	4.121	0.0537	1193	1.8038	648	1.5142	0.0324	1.535
S-i-S_09	1837	0.2828	4.240	0.0818	1139	1.4178	463	1.6454	0.0906	0.916
S-i-S_10	1704	0.2969	4.016	0.0650	1217	0.6882	242	1.7668	0.0868	1.121
S-i-S_11	1863	0.4209	7.320	0.0582	1634	0.3332	950	0.5608	0.0600	1.592
S-i-S_12	1662	0.4611	9.765	0.0766	1929	0.1483	593	4.4270	0.0562	1.364
S-i-S_13	1611	0.2977	3.950	0.0617	790	0.1098	1037	2.6625	0.0360	0.930
S-i-S_14	1911	0.3488	4.835	0.0626	1100	0.1263	747	0.3519	0.0938	0.927

Appendix 8.5: INAA data for agate artifacts from Harappa. Data in parts per million (PPM).
Context is noted as "S&D" if the artifact came from either surface or disturbed deposits.

sample	Artifact #	context	Al	Co	Cr	Eu	Fe	La	Na	Sb	Sc	V
AH-1	HM-2397	unknown	1863	0.1323	0.381	0.0015	341	0.6693	517	0.2701	0.2998	0.934
AH-2	HM-12414	unknown	1814	0.1143	0.457	0.0214	585	0.2731	622	0.2938	0.0149	1.295
AH-3	H90/3011-154	S&D survey, Mound E	3186	0.3578	1.246	0.0574	636	0.0722	999	0.1714	0.0168	1.564
AH-4	H90/3011-153	S&D survey, Mound E	3274	0.4720	2.504	0.0628	1233	0.0961	732	0.1073	0.2342	1.294
AH-5	H90/3030-87	S&D Tr. 58, Mound E	2070	0.3554	2.562	0.0733	921	0.1679	420	0.3633	0.0453	1.209
AH-6	H90/3037-63	S&D Tr. 58, Mound E	1936	0.3948	5.633	0.0750	1449	0.1111	469	0.2651	0.1820	2.150
AH-7	H90/3122-12	Period 3B Tr. 58, Mound E	2053	0.1341	0.381	0.0203	171	0.0329	344	0.1725	0.0199	0.818
AH-8	H90/3070-6	S&D Tr. 58, Mound E	6576	1.9976	5.360	0.0554	3426	2.2976	1321	0.3103	1.3337	13.607
AH-9	H90/3048-505	S&D Tr. 58, Mound E	1997	0.5095	4.363	0.0669	1578	0.0723	837	0.6152	0.0378	1.976
AH-10	H90/3068-19	S&D Tr. 58, Mound E	1983	0.4604	5.100	0.0759	1839	0.1258	599	0.2579	0.0997	1.519
AH-11	H90/3072-1	Period 3C Tr. 58, Mound E	2115	0.3336	3.815	0.0805	1269	0.2167	392	0.2629	0.0618	0.978
AH-12	H90/3200-36	S&D Tr. 59, Mound E	1741	0.3147	1.993	0.0512	605	0.0243	917	0.2766	0.0399	0.892

Appendix 8.5 (cont.): INAA data for agate artifacts from Harappa. Data in parts per million (PPM). Context is noted as "S&D" if the artifact came from either surface or disturbed deposits.

sample	**Artifact #**	**context**	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
AH-13	H90/3257-20	S&D Tr. 58, Mound E	1889	0.3713	4.390	0.0603	1244	0.1735	683	0.2784	0.0552	2.921
AH-14	H90/3124-13	Period 3B Tr. 56, Mound E	2552	1.0451	6.319	0.0359	3466	0.1431	459	0.2230	0.2133	19.490
AH-15	H90/3048-506	S&D Tr. 58, Mound E	3036	0.5456	0.748	0.0438	1107	0.1264	960	0.6165	0.2289	3.300
AH-16	H88/353-3	Period 3C Tr. 51	1869	0.1512	1.001	0.0262	153	0.0345	973	0.2746	0.0734	1.806
AH-17	H88/715-47	Period 3C Tr. 52	1730	0.1238	0.921	0.0229	158	0.0248	625	0.1568	0.0369	0.970
AH-18	H88/725-22	Period 3C Tr. 52	2028	0.2671	0.325	0.0273	343	0.0679	340	0.5850	0.0300	1.112
AH-19	H89/2023-9	Period 3B Tr. 52	1908	0.1890	0.411	0.0015	447	0.0063	162	0.3254	0.0093	1.047
AH-20	H90/3064-20	Period 3B Tr. 58	1685	0.1154	0.401	0.0184	491	0.1503	533	0.4243	0.1292	0.061
AH-21	H88/567-14	Period 3C Tr. 50	1965	0.1989	0.331	0.0230	468	0.0809	101	1.0273	0.0054	1.253
AH-22	H88/178-20	Period 3C Cemetery area	2120	0.1176	0.437	0.0330	231	0.0350	384	0.3175	0.0149	3.625
AH-23	H90/3022-28	S&D (likely 3B or 3C) Tr. 58, Mound E	2289	0.3177	0.547	0.0433	354	0.1890	578	0.1430	0.0554	2.571
AH-24	H96/7484-1	Period 2 Tr. 39, Mound AB	1888	0.2943	0.494	0.0406	401	0.0628	623	0.1530	0.1183	1.076

Appendix 8.6: INAA data for agate artifacts from Mehrgarh (AMR) and Nausharo (ANS).
Data in parts per million (PPM)

artifact	***Context [number]***	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
AMR-1	MR2 Surface	2520	0.0886	0.270	0.0259	80	0.0296	608	0.9750	0.0116	0.726
AMR-2	MR2 Surface	1952	0.0658	0.269	0.0218	93	0.0217	625	2.6377	0.0367	0.851
AMR-3	MR2 Surface	2499	0.1827	0.424	0.0193	149	0.1161	511	0.8508	0.2733	1.082
AMR-4	MR2 Surface	2048	0.0895	0.357	0.0151	67	0.0248	635	0.4956	0.0028	0.820
AMR-5	MR2 Surface	1893	0.0636	0.192	0.0189	37	0.0356	495	0.1006	0.0089	1.507
AMR-6	MR2 Surface	2146	0.0822	0.270	0.0184	31	0.0879	439	0.9987	0.0029	0.670
AMR-7	MR2 Surface	1727	0.0736	0.269	0.0011	57	0.0146	264	0.2232	0.1371	0.553
AMR-8	MR2 Surface	1859	0.0877	0.424	0.0245	74	0.0416	320	3.9236	0.0853	0.528
ANS-1	Nausharo IC/ID [NS I G8F 88.01.38]	2227	0.1234	0.192	0.0012	208	0.0285	437	0.1786	0.3155	1.805
ANS-2	Nausharo III [NS.90.09.06.26]	1952	0.2160	0.725	0.0218	194	0.0662	541	0.2278	0.0348	1.212
ANS-3	Nausharo IC [NS G4C (1) 86.18.26]	2433	0.1274	0.220	0.0228	287	0.0057	659	0.3759	0.0426	1.378
ANS-4	Nausharo III [NS.89.06.153]	2024	0.0806	0.251	0.0178	193	0.0058	225	0.2820	0.0588	0.679
ANS-5	Nausharo IC [NS I 87.4D.53]	1784	0.0839	1.250	0.0522	465	9.9652	160	1.3486	0.0360	0.695
ANS-6	Nausharo III [NS.96.06.35.13]	1789	0.0868	0.364	0.0274	156	0.0910	458	1.7987	0.0141	0.744
ANS-7	Nausharo III [NS.87.14.92]	1871	0.1400	0.315	0.0190	640	0.0799	243	0.2837	0.0319	1.328

Appendix 8.7: INAA data for agate artifacts from Mohenjo-daro (AMD), Chanhu-daro (ACD) and Nagwada (ANGW)
Data in parts per million (PPM)

artifact	**Al**	**Co**	**Cr**	**Eu**	**Fe**	**La**	**Na**	**Sb**	**Sc**	**V**
AMD-1	3234	0.3865	3.105	0.0715	1175	0.0925	1372	0.4993	0.0279	3.177
AMD-2	3514	0.2594	3.032	0.0715	803	0.0480	1671	1.2017	0.0199	1.811
AMD-3	2579	0.3747	1.833	0.3127	539	2.1685	822	0.1345	0.0983	1.797
AMD-4	1850	0.1835	0.757	0.0479	200	0.0901	992	0.1407	0.0462	1.871
AMD-5	2456	0.2908	2.622	0.0394	672	0.0450	908	0.1180	0.3899	5.594
AMD-6	2072	0.2022	0.938	0.0650	189	0.1038	1800	0.1649	0.0738	2.348
AMD-7	2041	0.1605	0.579	0.0399	246	0.0873	806	0.1596	0.0756	1.749
ACD-1	3444	0.6120	4.386	0.1439	1876	2.4948	705	0.2566	0.0528	6.439
ACD-2	3046	0.4871	4.056	0.0844	1405	0.1699	2374	0.1067	0.0705	3.596
ACD-3	1849	0.1639	1.223	0.0261	393	0.1031	1821	0.4212	0.0229	4.300
ACD-4	1642	0.1259	0.462	0.0198	541	0.0689	377	0.2913	0.0346	1.173
ACD-5	2710	0.2080	0.359	0.0239	320	0.0692	1162	0.6208	0.3494	2.811
ACD-6	3125	0.2691	0.854	0.0250	714	0.0390	1165	0.2161	0.1478	20.457
ACD-7	2168	0.3536	1.607	0.0662	556	0.0684	1344	0.2148	0.1420	8.426
ANGW-1	2892	0.3448	2.727	0.0522	1029	0.1254	335	0.1130	0.0332	2.431
ANGW-2	2290	0.2878	5.831	0.0395	753	0.6066	325	0.0977	0.1030	4.382
ANGW-3	2313	0.4096	3.028	0.0387	890	0.1768	722	0.2556	0.6969	3.040

Appendix 8.8: First predicted group memberships (PGMs) for agate artifacts generated from three CDAs in Chapter 8.

Artifact	*Figure 8.15*	*Figure 8.16*	*Figure 8.17B*
AH-1	S-i-S	S-i-S	n/a
AH-2	S-i-S	S-i-S	n/a
AH-3	GMB	Gujarat	GMB
AH-4	GMB	Gujarat	GMB
AH-5	GMB	Gujarat	GMB
AH-6	GMB	Gujarat	GMB
AH-7	GKK	Gujarat	GKK
AH-8	GKK	Gujarat	GKK
AH-9	S-i-S	S-i-S	n/a
AH-10	GMB	Gujarat	GMB
AH-11	GMB	Gujarat	GMB
AH-12	GMB	Gujarat	GMB
AH-13	GMB	S-i-S	n/a
AH-14	GRTP	Gujarat	GMB
AH-15	GKK	Gujarat	GKK
AH-16	GMB	Gujarat	GMB
AH-17	GMB	Gujarat	GMB
AH-18	GKK	Gujarat	GKK
AH-19	GKK	Gujarat	GKK
AH-20	S-i-S	S-i-S	n/a
AH-21	GKK	Gujarat	GKK
AH-22	GRTP	Gujarat	GRTP
AH-23	GKK	Gujarat	GKK
AH-24	GMB	Gujarat	GMB
ANGW-1	GRTP	Gujarat	GRTP
ANGW-2	GMB	Gujarat	GMB
ANGW-3	GMB	Gujarat	GMB

Artifact	*Figure 8.15*	*Figure 8.16*	*Figure 8.17B*
ACD-1	GMB	Gujarat	GMB
ACD-2	GMB	Gujarat	GMB
ACD-3	S-i-S	S-i-S	n/a
ACD-4	S-i-S	S-i-S	n/a
ACD-5	GMB	Gujarat	GMB
ACD-6	GMB	Gujarat	GMB
ACD-7	GMB	Gujarat	GMB
AMD-1	GMB	Gujarat	GMB
AMD-2	GMB	S-i-S	n/a
AMD-3	GMB	Gujarat	GMB
AMD-4	GMB	Gujarat	GMB
AMD-5	GMB	Gujarat	GMB
AMD-6	GMB	Gujarat	GMB
AMD-7	GMB	Gujarat	GMB
AMR-1	GKK	Gujarat	GKK
AMR-2	S-i-S	S-i-S	n/a
AMR-3	GKK	Gujarat	GKK
AMR-4	GKK	Gujarat	GKK
AMR-5	GKK	Gujarat	GMB
AMR-6	GKK	Gujarat	GKK
AMR-7	GKK	Gujarat	GKK
AMR-8	GRTP	Gujarat	GRTP
ANS-1	GKK	Gujarat	GKK
ANS-2	GKK	Gujarat	GMB
ANS-3	GMB	Gujarat	GMB
ANS-4	GRTP	Gujarat	GRTP
ANS-5	S-i-S	S-i-S	n/a
ANS-6	S-i-S	S-i-S	n/a
ANS-7	GKK	Gujarat	GKK

Appendix 8.9: Standardized canonical discriminant function coefficients for the scatter and box plots in Chapter 8 generated using canonical discriminant analysis.

Figures 8.14 & 15	*Function 1*	*Function 2*
Log Al	-.812	-.511
Log Co	-1.231	.766
Log Cr	.725	-.529
Log Eu	.183	-.586
Log Fe	.679	-.060
Log La	.018	.895
Log Na	1.008	.406
Log Sb	.009	.557
Log Sc	.403	-.578
Log V	-.047	-.067

Figure 8.16	*Function 1*
Log Al	-.682
Log Co	-.318
Log Cr	.025
Log Eu	-.333
Log Fe	.594
Log La	.689
Log Na	.667
Log Sb	.681
Log Sc	-.386
Log V	.077

Figure 8.17 A & B	*Function 1*	*Function 2*
Log Al	-.619	.899
Log Co	-1.280	-.845
Log Cr	1.062	.095
Log Eu	.461	.317
Log Fe	.246	.785
Log La	-.512	-.394
Log Na	1.052	-1.207
Log Sb	-.493	.383
Log Sc	.627	.053
Log V	-.045	.142

Appendix 9.1: EMPA of archaeological and geologic vesuvianite-grossular samples

Seven vesuvianite-grossular ornament manufacturing debris fragment from Harappa and five geologic samples from two vesuvianite-grossular sources in Pakistan (Muslimbagh ophiolite, Balochistan and Sakhakot-Qila ophiolite, NWFP) were examined using electron microprobe analysis (EMPA). Both the energy dispersive spectrometry (EDS) and the wavelength dispersive spectrometry (WDS) capabilities of the probe, as described in Chapter 2, were employed in these analyses.

Phases of vesuvianite and grossular garnet were distinguishable from one another because of their differing Mg contents (< 1% for grossular vs. 2 to 3 % for vesuvianite) as well as the consistently low composition totals (≈94-95%) for vesuvianite phases. The low vesuvianite totals are likely due in part to fact that Fluorine (F) was not one of the elements analyzed. Groat and others (1992) found F ranged up to 3.15% of the total in vesuvianites.

Archaeological Samples

H2000/9999-87, H2000/9999-88, H2000/9999-89 and H2000/9999-93

XRD had previously indicated that these fragments were composed of solely of vesuvianite. No inclusions or additional phases were identified during in the EDS or WDS analyses.

	H2000/ 9999-87 (n=7)	H2000/9999-88 (n=7)	H2000/9999-89 (n=7)	H2000/9999-93 (n=5)
MgO	2.75 %	2.99 %	2.77 %	2.61 %
Al_2O_3	17.62 %	18.36 %	17.73 %	17.22 %
SiO_2	35.86 %	36.32 %	35.89 %	36.18 %
CaO	36.21 %	36.33 %	36.45 %	35.71 %
TiO_2	0.01 %	0.00 %	0.01 %	0.03 %
MnO	0.03 %	0.08 %	0.07 %	0.05 %
FeO	2.32 %	0.97 %	2.08 %	2.82 %
Na_2O	0.00 %	0.00 %	0.00 %	0.01 %
K_2O	0.01 %	0.00 %	0.00 %	0.01 %
Cr_2O_3	0.01 %	0.01 %	0.00 %	0.07 %
Totals	*94.82 %*	*95.07 %*	*95.01 %*	*94.71 %*
Phase	**vesuvianite**	**vesuvianite**	**vesuvianite**	**vesuvianite**

H2000/9999-90

XRD analysis indicated that this fragment was primarily composed of vesuvianite and a significant secondary component of grossular garnet. This was confirmed by WDS.

	primary phase (average of 7 analyses)	secondary phase (average of 3 analyses)
MgO	2.75 %	0.19 %
Al_2O_3	18.85 %	21.84 %
SiO_2	36.16 %	38.45 %
CaO	36.28 %	37.13 %
TiO_2	0.02 %	0.03 %
MnO	0.01 %	0.07 %
FeO	0.74 %	0.95 %
Na_2O	0.00 %	0.00 %
K_2O	0.00 %	0.00 %
Cr_2O_3	0.02 %	0.02 %
Totals	*94.84 %*	98.69 %
Phase	**vesuvianite**	**grossular**

H98/8499-353

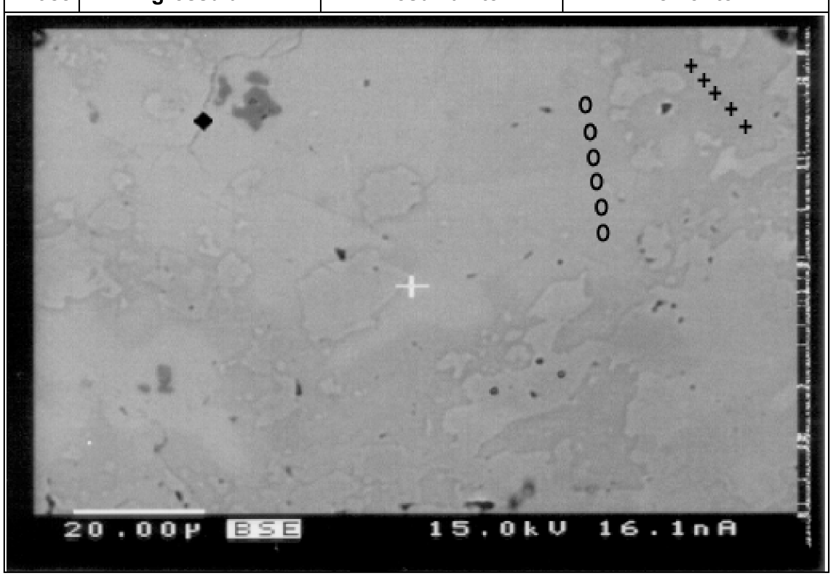
XRD analysis indicated that this fragment was composed of vesuvianite. Chlorite in fissures within the stone was detected by EDS and WDS. No other phases were identified.

	primary phase (average of 7 analyses)	fissure (1 analysis)
MgO	2.77 %	17.73 %
Al_2O_3	17.56 %	0.64 %
SiO_2	35.75 %	54.78 %
CaO	35.98 %	25.36 %
TiO_2	0.00 %	0.01 %
MnO	0.03 %	0.10 %
FeO	2.18 %	1.13 %
Na_2O	0.00 %	0.16 %
K_2O	0.00 %	0.00 %
Cr_2O_3	0.02 %	0.02 %
Totals	*94.30 %*	*99.92 %*
Phase	**vesuvianite**	**chlorite**

H2000/9999-91

XRD analysis indicated that this sample was primarily grossular garnet with traces of chlorite (variety clinochlore). WDS analyses confirmed the presence of both minerals and also detected a secondary vesuvianite phase. The image below the table indicates where the WDS scans were made on 12 points for three analyses (**0** = phase A, **+** = phase B, ♦ = phase C).

	analysis phase A (average of 6 analyses)	analysis phase B (average of 5 analyses)	fissure (phase C) (n=1)
MgO	0.01 %	2.55 %	18.1 %
Al_2O_3	22.03 %	17.83 %	0.2 %
SiO_2	38.64 %	35.46 %	55.0 %
CaO	37.19 %	36.09 %	25.4 %
TiO_2	0.03 %	0.02 %	0.0 %
MnO	0.08 %	0.04 %	0.0 %
FeO	1.01 %	2.13 %	0.6 %
Na_2O	0.00 %	0.01 %	0.0 %
K_2O	0.00 %	0.00 %	0.0 %
Cr_2O_3	0.02 %	0.01 %	0.0 %
totals	*99.01 %*	*94.14 %*	*99.4 %*
Phase	**grossular**	**vesuvianite**	**chlorite**



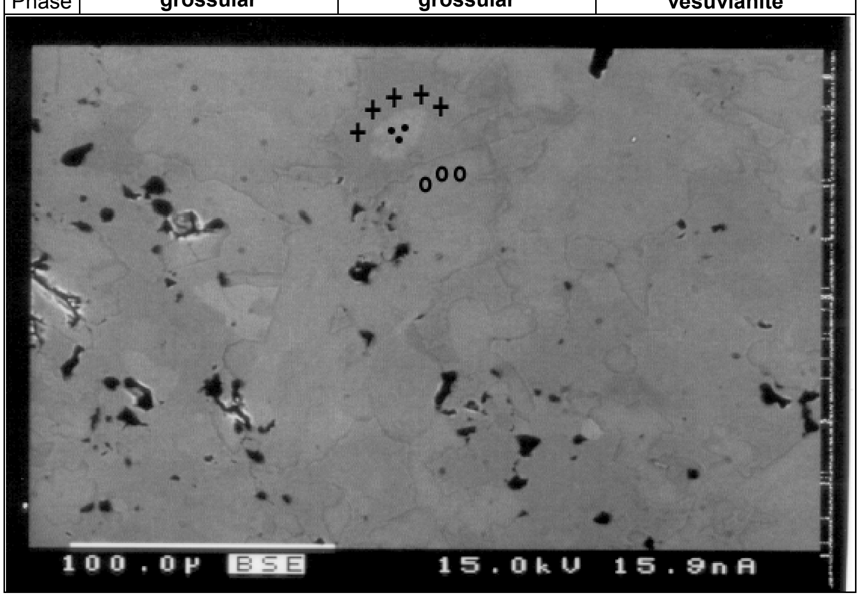
Geologic Samples

Sakhakot-Qila Ophiolite (Kot), NWFP

Three samples from this source formation were probed.

SQ-1. Specific gravity = 3.51. XRD analysis indicated that this sample was grossular. This was confirmed by WDS and a minor phase of vesuvianite was also detected. The image below indicates where the WDS scans were made on 11 points for three analyses (**0** = phase A, **+** = phase B, • = phase C). Note that the black patches in the image are voids rather than mineral phases.

	analysis phase A (n=3)	analysis phase B (n=5)	analysis phase C (n=3)
MgO	0.01 %	0.00 %	2.46 %
Al_2O_3	22.49 %	22.44 %	18.30 %
SiO_2	38.80 %	38.73 %	36.13 %
CaO	37.04 %	37.08 %	36.14 %
TiO_2	0.02 %	0.02 %	0.02 %
MnO	0.04 %	0.06 %	0.03 %
FeO	0.70 %	0.77 %	1.92 %
Na_2O	0.01 %	0.01 %	0.03 %
K_2O	0.01 %	0.01 %	0.01 %
Cr_2O_3	0.01 %	0.02 %	0.00 %
totals	*99.13 %*	*99.15 %*	*95.04 %*
Phase	**grossular**	**grossular**	**vesuvianite**



SQ-2. Specific gravity = 3.40. XRD analysis indicated that this sample was pure grossular. Small black inclusions are apparent in the stone's translucent milky green matrix. WDS confirmed that grossular was the primary component of this sample and revealed the inclusions to be chromite.

	primary phase (average of 7 analyses)	black inclusion (n=1)
MgO	0.01 %	7.99 %
Al_2O_3	22.84 %	23.79 %
SiO_2	38.61 %	0.06 %
CaO	37.02 %	0.17 %
TiO_2	0.03 %	0.30 %
MnO	0.07 %	0.00 %
FeO	0.20 %	26.61 %
Na_2O	0.01 %	0.01 %
K_2O	0.01 %	0.01 %
Cr_2O_3	0.00 %	39.11 %
totals	*98.79 %*	*98.06 %*
Phase	**grossular**	**chromite**

SQ-3. Specific gravity = 3.32. XRD analysis indicated that this sample was vesuvianite. This was confirmed was by WDS. No other phases or inclusions were identified.

	primary phase (average of 7 analyses)
MgO	3.10 %
Al_2O_3	17.65 %
SiO_2	35.41 %
CaO	36.39 %
TiO_2	0.03 %
MnO	0.07 %
FeO	1.75 %
Na_2O	0.01 %
K_2O	0.01 %
Cr_2O_3	0.00 %
totals	*94.42 %*
Phase	**vesuvianite**

Muslimbagh Ophiolite (Taleri Mohammed Jan), Balochistan

Two samples from this source formation were probed.

QB-1. Specific gravity = 3.33. XRD analysis on a sample of this material indicated that it is composed of vesuvianite and grossular. WDS analysis was only performed on the sample's major phase, which was vesuvianite.

TMJ-1. Specific gravity = 3.26. XRD analysis indicated that the sample was composed of vesuvianite with some chlorite (variety clinochlore). EDS and WDS confirmed this but found no evidence of grossular phases or chromite inclusions.

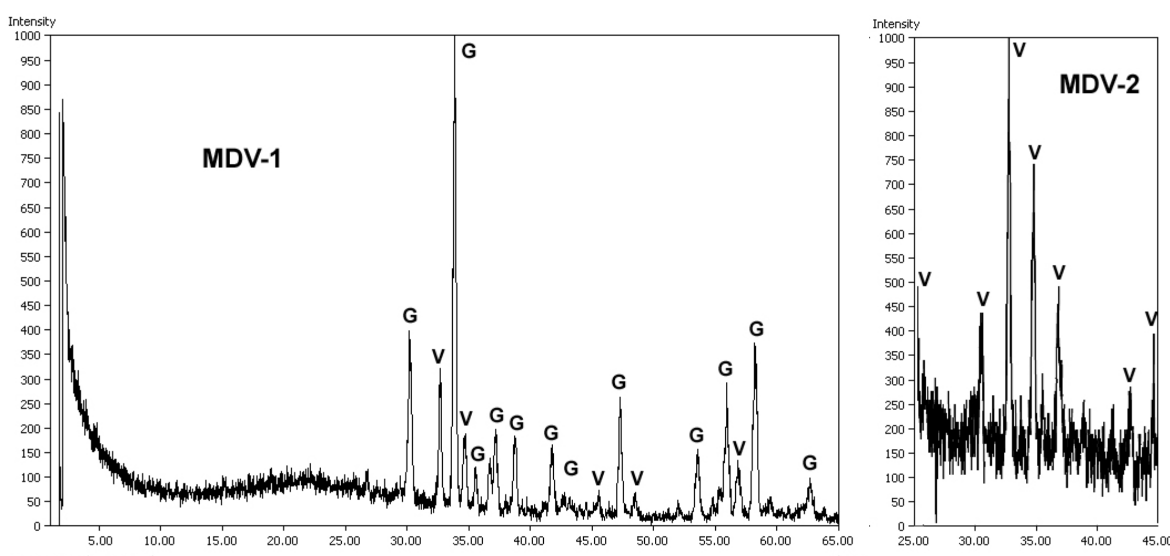
	QB-1 (average of 7 analyses)	TMJ-1 (average of 7 analyses)
MgO	2.51 %	2.8 %
Al_2O_3	17.40 %	15.9 %
SiO_2	36.11 %	35.7 %
CaO	35.50 %	35.3 %
TiO_2	0.39 %	0.3 %
MnO	0.03 %	0.1 %
FeO	2.52 %	3.7 %
Na_2O	0.00 %	0.0 %
K_2O	0.00 %	0.0 %
Cr_2O_3	0.01 %	0.0 %
totals	*94.47 %*	93.8 %
Phase	**vesuvianite**	**vesuvianite**

Appendix 9.2: Analyses of vesuvianite-grossular fragments from Mohenjo-daro

Six vesuvianite-grossular ornament manufacturing debris fragments from Mohenjo-daro were examined using XRD analysis and SG testing. The results are in the following table:

XRD & SG testing results for six samples		
Sample	*Phase(s)*	*Specific gravity*
MDV 1	grossular-vesuvianite	3.41
MDV 2	vesuvianite	3.28
MDV 3	vesuvianite	3.30
MDV 4	vesuvianite	3.28
MDV 5	vesuvianite	3.29
MDV 6	vesuvianite	3.24

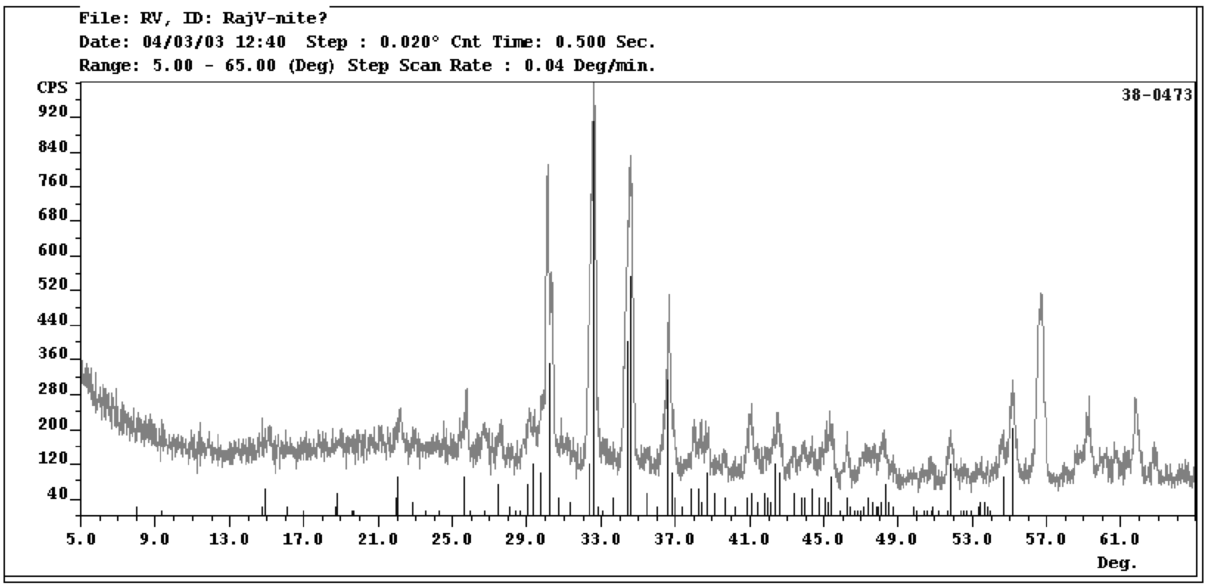
The XRD scan for sample MDV-1 (below left) was conducted at 2-theta 5° to 65°. All others were run only from 2-theta 25° to 45° as this was sufficient to identify and distinguish both vesuvianite and grossular. Only MDV-2 is presented here (below right) as the scans for MDV-2 through MDV-6 are basically identical.



(G = **Grossular** peak, V = **Vesuvianite** peak)

Appendix 9.3: XRD of massive vesuvianite from Kumbhalgarh Forest, Rajasthan

The XRD profile for this samples indicated that is composed of vesuvianite (vertical lines indicate vesuvianite peaks). No grossular peaks are present.



Appendix 9.4: INAA data for vesuvianite-grossular samples from Harappa and Mohenjo-daro (MDV)
Elemental concentrations in parts per million

Artifact	**Period**	**Mound**	**Trench**	**Al**	**Ce**	**Co**	**Cr**	**Eu**	**Fe**	**Mn**	**Na**	**Sc**	**Sm**	**Sr**	**U**	**V**
H96/7327-2	5	AB	38	110623	2.74	18.99	586	0.224	20302	715	79.9	74.66	0.050	650	0.507	341
H99/9730-11	3C	F	43	109543	0.89	12.63	33.0	0.051	13280	870	53.1	3.95	0.006	623	0.132	36.2
H96/7129-1	3C	E	36	92188	3.61	27.20	878	0.414	20792	470	109	134.5	0.060	518	0.642	471
H94/5302-81	3C	ET	22	96097	1.59	24.53	269.5	0.126	19943	572	103	24.60	0.009	509	0.252	108
H94/4898-83	3C	ET	27	93140	0.80	10.78	3.72	0.093	18619	359	73.7	0.32	0.006	432	0.094	5.0
H96/6958-41	3B	E	11	101568	1.93	40.74	686	0.154	28103	593	151	32.99	0.075	536	0.308	86.0
H98/8908-8	1	AB	39	108235	0.96	21.96	27.0	0.087	22530	475	144	3.19	0.005	485	0.133	23.2
MDV-1	Surface	Moneer Area	n/a	95973	1.28	16.56	103	0.108	18567	452	301	18.23	0.021	443	0.194	79.6
MDV-2	Surface	Moneer Area	n/a	93137	1.62	17.13	163	0.141	19151	418	329	27.52	0.021	465	0.255	115
MDV-3	Surface	Moneer Area	n/a	96364	0.85	13.70	13.6	0.086	18387	442	72.3	2.15	0.004	466	0.109	14.2

Appendix 9.5: INAA data for vesuvianite-grossular samples from Sakhakot-Qila (NWFP-SQ) and Taleri Mohammed Jan (B-TMJ)
Elemental concentrations in parts per million

Sample	**Al**	**Ce**	**Co**	**Cr**	**Eu**	**Fe**	**Mn**	**Na**	**Sc**	**Sm**	**Sr**	**U**	**V**
NWFP-SQ-01	136093	0.84	2.67	44.3	0.142	7595	524	203	1.585	0.037	556	0.119	7.80
NWFP-SQ-02	137086	0.72	1.44	9.64	0.137	5254	440	208	0.440	0.021	528	0.090	6.58
NWFP-SQ-03	110213	0.86	11.9	6.84	0.113	15295	723	87.8	2.499	0.078	582	0.128	18.3
NWFP-SQ-04	112945	0.95	14.4	41.2	0.110	13266	470	63.0	4.637	0.096	520	0.151	27.9
NWFP-SQ-05	155226	0.91	4.21	209.1	0.134	5714	918	76.9	2.139	0.061	689	0.121	14.4
NWFP-SQ-06	164444	0.85	1.60	120.0	0.234	6087	649	74.1	2.083	0.114	611	0.119	11.6
B-TMJ-01	94495	0.96	22.3	3.21	0.883	35350	772	71.5	0.375	0.254	549	0.140	18.8
B-TMJ-02	87390	0.75	10.3	1.22	0.279	26161	574	29.9	0.177	0.005	495	0.111	17.8
B-TMJ-03	87073	0.96	13.1	2.22	0.551	35870	813	48.3	0.722	0.489	562	0.168	28.2
B-TMJ-04	89308	0.53	3.37	0.72	0.278	7814	703	12.2	0.694	0.019	529	0.098	61.0
B-TMJ-05	86622	0.96	13.2	3.65	0.649	36781	839	53.7	1.828	0.187	571	0.184	36.8
B-TMJ-06	85458	0.87	12.5	3.69	0.541	34712	814	47.9	0.338	0.065	567	0.208	16.0
B-TMJ-07	91995	0.92	16.9	2.79	0.767	35987	733	70.8	0.402	0.238	546	0.222	19.7
B-TMJ-08	94171	1.22	10.1	10.4	0.379	17953	283	119	24.18	0.331	402	0.253	11.8
B-TMJ-09	95638	1.09	9.26	6.58	0.292	18015	331	125	18.00	0.227	421	0.223	10.9

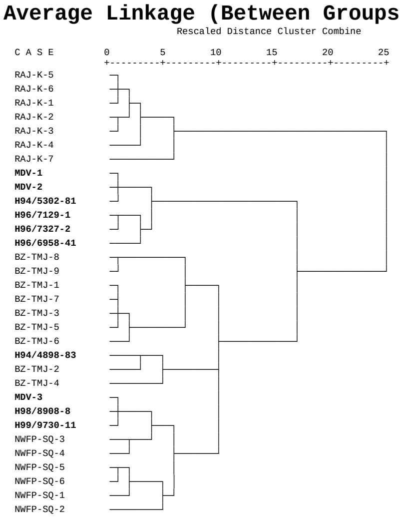
Appendix 9.6: INAA data for vesuvianite-grossular samples from Kumbhalgarh Forest Reserve, Rajasthan (Raj-K) Elemental concentrations in parts per million													
sample	**Al**	**Ce**	**Co**	**Cr**	**Eu**	**Fe**	**Mn**	**Na**	**Sc**	**Sm**	**Sr**	**U**	**V**
RAJ-K-01	75650	6.77	3.89	18.3	0.509	24501	313	28.8	7.266	1.072	939	0.378	18.7
RAJ-K-02	75342	9.25	8.82	47.7	1.169	38017	315	43.3	13.20	4.327	1076	0.791	15.5
RAJ-K-03	73890	14.67	7.45	70.1	0.811	40296	313	43.2	16.23	3.238	738	0.916	23.1
RAJ-K-04	73184	41.06	8.09	11.9	0.712	35635	317	58.1	3.843	2.628	1132	0.737	9.81
RAJ-K-05	74511	8.41	12.4	33.3	0.555	41636	350	41.8	4.816	1.256	931	0.440	20.1
RAJ-K-06	72398	8.75	10.0	18.7	0.610	40853	351	47.6	4.763	1.291	761	0.494	19.3
RAJ-K-07	80427	116.3	8.48	59.9	1.253	42754	338	55.0	18.20	7.021	1446	2.485	18.0

Appendix 9.7: Standardized canonical discriminant function coefficients for Figure 9.8

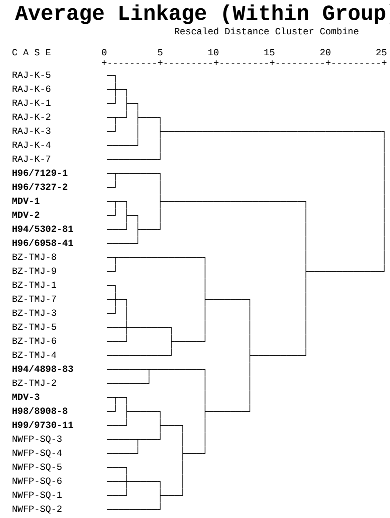
Element	*Function 1*	*Function 2*
Log Al	2.164	-.723
Log Ce	.066	.855
Log Co	.357	-1.367
Log Cr	-1.227	1.814
Log Eu	-1.243	-1.776
Log Fe	.304	.598
Log La	-2.079	-1.297
Log Mn	.811	-.985
Log Na	1.843	1.386
Log Sc	-.341	-2.036
Log Sm	1.420	2.271
Log U	-.163	1.238
Log V	.818	-.922

Appendix 9.8: Six alternate clustering strategies using the vesuvianite-grossular comparative data

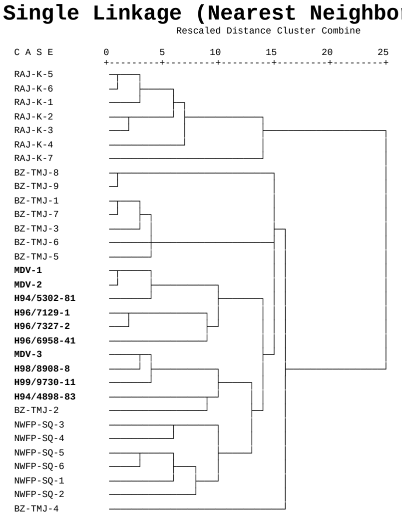
Average Linkage (Between Groups)



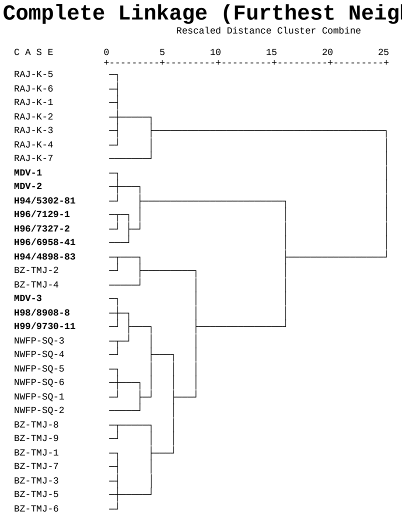
Average Linkage (Within Group)



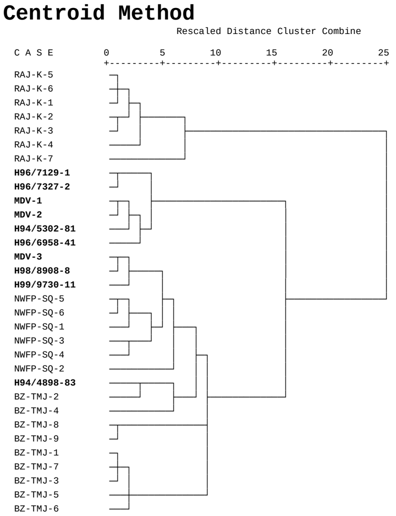
Single Linkage (Nearest Neighbor)



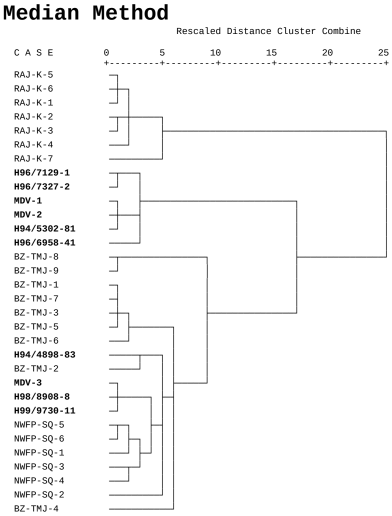
Complete Linkage (Furthest Neighbor)



Centroid Method



Median Method



Appendix 9.9: Is the vesuvianite-grossular / "Ernestite" association genuine?

In Chapter 9, I showed that the spatial and temporal distribution patterns of "Ernestite" and vesuvianite-grossular artifacts at Harappa are practically mirror images of one another. With the exception of a single and possibly anomalous vesuvianite-grossular flake in Period 1 levels, each variety of stone begins to appear in the site's archaeological record around periods 3B and 3C. Both are varieties are found mainly on mounds E and ET. Moreover, when association at the level of shared stratigraphically secure excavation lot is considered, we see that in roughly one out of every three lots (32.4%) in which an "Ernestite" artifact was recovered a vesuvianite-grossular artifact was also present. I argue that it is no coincidence that each material appears at exactly the same time *when* (ca. periods 3B and 3C) and, largely, in the same places *where* (Mound E/ET) beadmakers were using the other one. Simply put, the reason is that vesuvianite-grossular beads could not have been drilled without use of "Ernestite" bits. Whether or not the discovery of "Ernestite" and its unique drilling properties (discussed in Appendix 4.5) finally allowed beadmakers to use vesuvianite-grossular or if desire to use vesuvianite-grossular necessitated the development of "Ernestite" is a "chicken and egg" type question. Who knows? They both appear at the same time and place.

However, is this association indeed *genuine*? That is, does the evident spatial and temporal pattern stem from the actual behaviors of Harappans? Or, could it be a product of something else? As I discussed in detail in Chapter 4, Harappa's rock and mineral assemblage is unevenly distributed through time and space. Some of this is due to the physical constraints of the site (Harappa's deeply buried early occupation levels) while

some is due to the research strategies of the HARP excavators (an early and sustained focus on mounds E and ET). Although I think that in Chapter 9 I satisfactorily demonstrated the vesuvianite-grossular / "Ernestite" association to be valid despite the possibility of recovery bias, here I present some additional, supplementary observations regarding this issue.

First recall Figure 4.10, which in its second column shows how all of Harappa's rock and mineral artifacts from secure contexts (n = 32,365) are distributed through each chronological phase. The distributional bias toward Period 3C at the expense of earlier levels is clear. Now look at Figure 4.12, which shows the spatial and temporal presence or absence of all rock and mineral varieties at Harappa in order of decreasing abundance in the assemblage. The rock and mineral sub-assemblages from the early levels are clearly not as diverse as Period 3C. Part of the reason for this, I have argued, is because the less abundant overall varieties (those at the bottom of the table) were not as apt to be recovered in those levels. However, "Ernestite" and, in particular, vesuvianite-grossular have fairly sizeable sub-assemblages. If those stones were used to any significant degree (or if at all) prior to Period 3B then I would expect at least a few examples to have been recovered from Early Harappan and Period 3A levels. For Appendix 9.9 Figure 1 (next page), I used the overall rock and mineral assemblage temporal distribution percentages from the second column of Figure 4.10 as a formula for making (admittedly) crude predictions of the number of artifacts that might be expected in each phase for those material varieties and a select number of others. If vesuvianite-grossular was used and discarded throughout the entire sequence at Harappa, then perhaps 45 or so examples out of the 180 artifacts in that material sub-assemblage from secure-contexts might be expected to have been recovered

Appendix 9.9 Figure 1: The *predicted* temporal distribution of select rock and mineral varieties in secure contexts based on overall assemblage distribution versus the *actual* temporal distribution of those varieties

Period	*rock & mineral assemblage Distribution (n = 32,365)*	predicted **vesuvianite** distribution (n=180)	actual **vesuvianite** distribution (n=180)	predicted **"Ernestite"** distribution (n=40)	actual **"Ernestite"** distribution (n=40)
1	11.59%	21	1	4.6	0
2	7.95%	14	0	3.2	0
3A	6.10%	11	0	2.4	0
3B	10.88%	20	4	4.4	2
3C	62.81%	113	174	25.1	38
4/5	0.67%	1	1	0.3	0

Period	*rock & mineral assemblage Distribution (n = 32,365)*	predicted **igneous** distribution (n=252)	actual **igneous** distribution (n=252)	predicted **alabaster** distribution (n=212)	actual **alabaster** distribution (n=212)
1	11.59%	29.2	3	24.6	3
2	7.95%	20.0	13	16.9	3
3A	6.10%	15.4	7	12.9	9
3B	10.88%	27.4	34	23.1	18
3C	62.81%	158.3	192	133.2	179
4/5	0.67%	1.7	3	1.4	0

Period	*rock & mineral assemblage Distribution (n = 32,365)*	predicted **lapis lazuli** distribution (n=75)	actual **lapis lazuli** distribution (n=75)	predicted **amazonite** distribution (n=12)	actual **amazonite** distribution (n=12)
1	11.59%	8.7	4	1.7	3
2	7.95%	6.0	11	1.2	2
3A	6.10%	4.6	2	0.9	0
3B	10.88%	8.2	24	1.6	2
3C	62.81%	47.1	32	9.4	5
4/5	0.67%	0.5	2	0.1	3

from levels prior to Period 3B. However, with the exception of the single and possibly anomalous flake from Period 1 (this instance detailed in Chapter 9), none were. Likewise, no "Ernestite" artifacts whatsoever were recovered from the early periods in question, although perhaps around ten examples might have been expected. For the purpose of comparison, I have applied the same formula to other rock and mineral varieties having sub-assemblages of comparable sizes – igneous rock and alabaster for vesuvianite-grossular and lapis lazuli and amazonite for "Ernestite." Although the predicted versus the actual distributions for those materials did not always correspond to one another (indicating that overall assemblage distribution is not a good predictor of the distribution of any one material type), it was almost always the case that some examples of those materials were recovered from pre-Period 3B chronological phases. This suggests to me that the absence (or near absence) of vesuvianite-grossular and "Ernestite" from early levels at Harappa is probably not due to recovery bias alone. These rock varieties were simply not used at during those phases.

Next we turn to my contention that Harappans living and working on mounds E and ET were the primary users of vesuvianite-grossular and "Ernestite." Figure 4.9 from Chapter 4 indicates that 66% of the rock and mineral assemblage at Harappa was recovered from excavation or survey on the combined area of those two mounds (Mound E/ET). This shows that there is unquestionably a recovery bias toward the area of the site where vesuvianite-grossular and "Ernestite" artifacts are most heavily concentrated. However, is it enough to account for the fact that around 90% of both rock varieties were recovered from those mounds? For Appendix 9.9 Figure 2 (next page), I have used the used the

Appendix 9.9 Figure 2: The *predicted* spatial distribution of select rock and mineral varieties across the mounds at Harappa based on overall assemblage distribution versus the *actual* spatial distribution of those varieties.

Mound	*rock & mineral assemblage Distribution (n=56,350)*	predicted **vesuvianite** distribution (n=534)	actual **vesuvianite** distribution (n=543)	predicted **"Ernestite"** distribution (n=75)	actual **"Ernestite"** distribution (n=75)
AB	19.54%	106.1	5	14.7	4
E	40.14%	218.0	300	30.1	30
ET	26.51%	143.9	190	19.9	37
F	6.73%	36.5	5	5.0	1
Off	7.08%	38.4	43	5.3	3

Mound	*rock & mineral assemblage Distribution (n=56,350)*	predicted **igneous** distribution (n=455)	actual **igneous** distribution (n=455)	predicted **alabaster** distribution (n=422)	actual **alabaster** distribution (n=422)
AB	19.54%	88.9	95	82.5	154
E	40.14%	182.6	158	169.4	61
ET	26.51%	120.6	76	111.9	124
F	6.73%	30.6	97	28.4	55
Off	7.08%	32.2	29	29.9	28

Mound	*rock & mineral assemblage Distribution (n=56,350)*	predicted **lapis lazuli** distribution (n=174)	actual **lapis lazuli** distribution (n=174)	predicted **amazonite** distribution (n=21)	actual **amazonite** distribution (n=21)
AB	19.54%	34.0	74	3.9	13
E	40.14%	69.8	48	8.0	0
ET	26.51%	46.1	15	5.3	4
F	6.73%	11.7	12	1.3	3
Off	7.08%	12.3	25	1.4	1

assemblage spatial distribution percentages for the entire assemblage of rock and mineral artifacts (Figure 4.9) to make crude predictions about how vesuvianite-grossular, “Ernestite,” and the selected sub-assemblages of comparable size was be distributed if they were being used more or less to the same degree in all parts of the site. Although once again the predicted distributions and the actually distributions for the comparable sub-assemblages do not always match perfectly, none of them are as sharply biased toward mounds E-ET as vesuvianite-grossular and “Ernestite” clearly area. This leads me to conclude that the spatial patterning of the latter two materials is, at least partially, a genuine product of behaviors of ancient residents of Harappa.

Appendix 10.1: Sulfur and strontium isotope values for alabaster artifacts from Harappa, Mohenjo-daro, Rehman Dheri and Musa Khel						
Site	**Artifact**	**Sample number**	**Period**	**Mound-Trench**	**δ34S ‰**	**Sr 87/86**
Harappa	fragment	H2000/9572-22	2	AB - 39	34.769	0.710059
Harappa	fragment	H98/8486-84	2	AB - 39	28.664	0.711125
Harappa	bangle	H2000/2126-9	3A	E - 54	14.245	0.711609
Harappa	fragment	H95/4686-7	3B	ET - 10	26.488	0.714056
Harappa	fragment	H94/4469-406	3B	ET - 10	23.402	0.712165
Harappa	fragment	H95/7018-11	3C	AB - 31	25.756	0.712064
Harappa	fragment	H98/8308-170	3C	AB - 39	36.223	0.708499
Harappa	fragment	H98/8310-64	3C	AB - 39	20.128	0.709541
Harappa	fragment	H98/8327-16	3C	AB - 39	23.602	0.708272
Harappa	ringstone	H98/7715-9	3C	AB - 42	21.971	0.709034
Harappa	fragment	H2001/11502-3	3C	E - 11	27.465	0.710068
Harappa	vessel	H99/8890-93	3C	E - 11	21.293	0.712989
Harappa	bangle	H2000/2207-20	3C	E - 54	21.116	0.710131
Harappa	plug	H2000/2733-16	3C	E - 55	18.674	0.713016
Harappa	fragment	H94/3987-32	3C	E - 7/8	14.933	0.708542
Harappa	fragment	H95/4731-2	3C	ET - 19	20.039	0.709318
Harappa	fragment	H95/4921-12	3C	ET - 28	21.260	0.711188
Harappa	fragment	H95/4954-19	3C	ET - 28	23.624	0.708876
Harappa	fragment	H95/5729-151	3C	ET -32	19.640	0.711863
Harappa	fragment	H2000/10046-5	3C	F - 43	21.460	n/a
Harappa	fragment	H98/8631-2	3C	F - 43	23.358	0.707956
Harappa	fragment	H99/9765-2	3C	F - 43	21.615	0.708487
Harappa	fragment	H99/8387-107	surface	AB - 39	23.624	0.713547
Harappa	vessel	H2000/2102-907	surface	E - 54	21.249	n/a
Harappa	bangle	H2000/2139-128	surface	E - 54	20.505	0.712308
Harappa	fragment	H96/7218-10	surface	F - 37	22.881	0.708216
Harappa	pendent	H94/4999-511	unknown	unknown	19.784	0.709347
Harappa	ball	Vats 3558	unknown	AB?	19.107	n/a
Harappa	weight	Vats 13799	unknown	AB?	22.459	0.708033
Mohenjo-daro	vessel	MD-1	surface	DK area	16.820	0.708719
Musa Khel	fragment	MK-1	surface	n/a	31.128	0.708490
Musa Khel	fragment	MK-2	surface	n/a	26.832	0.712666
Rehman Deri	fragment	RD-1	surface	n/a	25.500	0.709975

Appendix 10.2: Sulfur and strontium isotope values for geologic samples of alabaster from sources in the Sulaiman Mountains, Salt Range and Kohat					
Sample	**Region (Province)**	**Source/Location**	**Age**	**δ^{34}S ‰**	**Sr 87/86**
BG19	Sulaimans (Balochistan)	Bala Dhaka - Karher	Eocene	22.337	0.707846
BG-20	Sulaimans (Balochistan)	Bala Dhaka - Karher	Eocene	22.193	0.707778
BG21	Sulaimans (Balochistan)	Barkhan	Eocene	22.725	0.707793
BG-13	Sulaimans (Balochistan)	Chamlang Mari	Eocene	22.559	0.707784
BG-14	Sulaimans (Balochistan)	Chamlang Mari	Eocene	22.592	0.707805
BG-04	Sulaimans (Balochistan)	Dera Bugti	Eocene	23.414	0.707750
BG-05	Sulaimans (Balochistan)	Dera Bugti	Eocene	23.458	0.707817
BG-03	Sulaimans (Punjab)	DG Khan - Zinda Pir	Eocene	24.102	0.707766
DGK-2	Sulaimans (Punjab)	DG Khan - Zinda Pir	Eocene	23.769	n/a
BG-08	Sulaimans (NWFP)	DI Khan - Drazinda	Eocene	22.415	0.707825
BG-09	Sulaimans (NWFP)	DI Khan - Drazinda	Eocene	20.594	0.707835
DIK-3	Sulaimans (NWFP)	DI Khan - Drazinda	Eocene	23.025	n/a
DIK-4	Sulaimans (NWFP)	DI Khan - Drazinda	Eocene	22.847	n/a
BG17	Sulaimans (Balochistan)	Kore More	Eocene	23.402	0.707825
BG18	Sulaimans (Balochistan)	Kore More	Eocene	23.669	0.707824
BG-22	Sulaimans (Balochistan)	Kurcha-Rakni	Eocene	22.792	0.707745
BG-06	Sulaimans (Balochistan)	Lakha Kach-Rakni	Eocene	22.903	0.707824
BG-07	Sulaimans (Balochistan)	Lakha Kach-Rakni	Eocene	23.214	0.707805
BG-10	Sulaimans (Balochistan)	Nisau-Vitakri	Eocene	23.769	0.707779
BG-11	Sulaimans (Balochistan)	Nisau-Vitakri	Eocene	23.647	0.707804
BG-15	Sulaimans (Balochistan)	Nodo	Eocene	23.824	0.707785
BG-16	Sulaimans (Balochistan)	Nodo	Eocene	24.202	0.707795
BG-01	Sulaimans (Balochistan)	Spintangi	Eocene	24.890	0.707704
BG-02	Sulaimans (Balochistan)	Spintangi	Eocene	24.612	0.707748
KJ-1	Kohat (NWFP)	Jatta	Eocene	19.173	0.707906
KJ-2	Kohat (NWFP)	Jatta	Eocene	19.029	0.708949
KBK-1	Kohat (NWFP)	Bahad-ur-Khel	Eocene	19.118	0.707747
KBK-2	Kohat (NWFP)	Bahad-ur-Khel	Eocene	20.084	n/a
SRL-1	Salt Range (Punjab)	6km north of Lille	Infra-Cambrian	37.699	0.709053
SRL-2	Salt Range (Punjab)	6km north of Lille	Infra-Cambrian	37.400	0.709021
BK-1	Salt Range (Punjab)	Buri Khel	Infra-Cambrian	36.745	0.708139
BK-2	Salt Range (Punjab)	Buri Khel	Infra-Cambrian	36.722	0.708048
BK-3	Salt Range (Punjab)	Buri Khel	Infra-Cambrian	36.878	0.708152
SRDK-1	Salt Range (Punjab)	Daud Khel	Eocene	25.278	0.711878
SRDK-2	Salt Range (Punjab)	Daud Khel	Eocene	25.467	0.711899
SRDK-3	Salt Range (Punjab)	Daud Khel	Eocene	25.334	n/a
JSR-1	Salt Range (Punjab)	Jalalpur	Infra-Cambrian	31.539	0.710204
JSR-2	Salt Range (Punjab)	Jalalpur	Infra-Cambrian	34.036	0.708770
JSR-3	Salt Range (Punjab)	Jalalpur	Infra-Cambrian	34.480	n/a
KDSR-1	Salt Range (Punjab)	Katha Dome	Infra-Cambrian	30.151	0.708570
KDSR-2	Salt Range (Punjab)	Katha Dome	Infra-Cambrian	30.751	0.708543
KDSR-3	Salt Range (Punjab)	Katha Dome	Infra-Cambrian	30.762	n/a
SRK-2	Salt Range (Punjab)	Khewra	Infra-Cambrian	35.957	0.708059
SWN-1	Salt Range (NWFP)	Saiduwali Nala	Eocene	26.488	0.711462
SWN-2	Salt Range (NWFP)	Saiduwali Nala	Eocene	26.444	0.710686
SWN-3	Salt Range (NWFP)	Saiduwali Nala	Eocene	26.621	0.711447

Appendix 10.3: List of pink bi-pyramidal quartz crystals (Mari "Diamonds") from Harappa			
artifact (year-lot-record)	**mound / area**	**trench / context**	**period**
H86/0.031-20	E - western slope	surface	unknown
H86/17-8	Cemetery	Harappan dump	3C
H89/2024-16	E	52	3B
H89/2025-5	E	52	3B
H93/3516-34	E	4	3 or later
H94/4814-53	ET	19	3 or later
H95/5166-55	E	7_8	3C
H96/6219-36	ET	35	3C
H96/7401-60	AB	39	2/3 mix
H96/7467-613	AB	39	2/3 mix

Appendix 11.1: Archaeological limestone samples from Harappa analyzed for this study. UPPERCASE indicates analysis variety.

sample #	artifact #	artifact type	texture	color
HLS-001	H89/1063-28	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-002	H2000/9999-72	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-003	H2000/2091-35	fragment	MICRITIC	Very pale orange 10YR 8/2 rapidly blending to Grayish red 5Y 4/2
HLS-004	H2000/2500-3	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-005	H2000/2085-7	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6 to Pale reddish brown 10R 5/4
HLS-006	H95/7008-12	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-007	Vats (no #)	ringstone	sandy	BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2
HLS-008	Vats (no #)	ringstone	sandy	BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2
HLS-009	H95/7110-4	fragment	MICRITIC	Grayish orange 10YR 7/4 with some black spots
HLS-010	H2001/9613-7	shaped stone	MICRITIC	Pale yellowish brown 10YR 6/2 mottled Grayish orange 10YR 7/4
HLS-011	H86/0.025-123	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-012	H93/3862-9	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2
HLS-013	H93/3892-15	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-014	H93/3892-56	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6 to Pale reddish brown 10R 5/4
HLS-015	H94/667-1	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6
HLS-016	H94/3937-1	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-017	H95/4940-106	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-018	H95/5170-57	fragment	sandy	Grayish red 10R 4/2 (BANDED group)
HLS-019	H95/5170-58	fragment	sandy	Grayish red 10R 4/2 to Moderate yellowish brown 10YR 5/4 (BANDED group)
HLS-020	H95/5195-12	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6
HLS-021	H95/7017-3	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-022	H96/7150-5	fragment	sandy	Dark yellowish orange 10YR 6/6 to Moderate reddish brown 10R 4/6 (BANDED group)
HLS-023	H96/7218-5	fragment	sandy	Dark yellowish orange 10YR 6/6 to Moderate reddish brown 10R 4/6 (BANDED group)
HLS-024	H98/8306-20	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6

Appendix 11.1(cont.): Archaeological limestone samples from Harappa analyzed for this study. UPPERCASE indicates analysis type

sample #	artifact #	artifact type	texture	color
HLS-025	H98/8334-261	fragment	sandy	Dark YELLOWish orange 10YR 6/6 to Moderate reddish brown 10R 4/6
HLS-026	H98/8324-19	fragment	sandy	Dark YELLOWish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-027	H98/8324-14	fragment	sandy	Dark YELLOWish orange 10YR 6/6 to Grayish orange 10YR 7/4
HLS-028	H98/8310-147	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-029	H98/8308-138	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2
HLS-030	H98/8313-116	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-031	H98/8323-49	fragment	sandy	Dark YELLOWish orange 10YR 6/6
HLS-032	H98/8335-37	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-033	H98/8331-68	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-034	H98/8321-2	ringstone frag.	sandy	Dark YELLOWish orange 10YR 6/6 to Moderate reddish brown 10R 4/6
HLS-035	H98/8306-257	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-036	H98/8303-36	fragment	sandy	Moderate yellowish brown 10YR 5/4 (BANDED group)
HLS-037	H99/9724-50	fragment	sandy	Moderate yellowish brown 10YR 5/4 to Dark yellowish brown 10YR 4/2
HLS-038	H99/9722-16	fragment	sandy	Dark YELLOWish orange 10YR 6/6
HLS-039	H2000/2091-36	fragment	sandy	Dark yellowish orange 10YR 6/6 (BANDED group)
HLS-040	H2000/2520-3	fragment	sandy	BANDED Dark yellowish orange 10YR 6/6 to Pale brown 5YR 5/2
HLS-041	Vats (T#148)	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-042	Vats (T#149)	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-043	Vats (T#150)	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-044	Vats # 4534	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-045	Vats (T#152)	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-046	HM#10548	shaped stone	sandy	Dark YELLOWish orange 10YR 6/6
HLS-047	HM#88798	door pivot?	fine sandy	Grayish Orange 10YR 7/4 (BANDED group)
HLS-048	H96/7401-2	fragment	fine sandy	Moderate reddish brown 10R 3/4 (YELLOW group)

Appendix 11.1(cont.): Archaeological limestone samples from Harappa analyzed for this study. UPPERCASE indicates analysis type				
sample #	**artifact #**	**artifact type**	**texture**	**color**
HLS-049	H96/7307-1	ringstone frag.	fine sandy	Moderate reddish brown 10R 3/4 (YELLOW group)
HLS-050	H98/8334-4	fragment	fine sandy	Pale reddish brown 10R 5/4 (YELLOW group)
HLS-051	H98/8334-3	fragment	fine sandy	Pale reddish brown 10R 5/4 (YELLOW group)
HLS-052	H2000/2088-101	fragment	MICRITIC	Pale brown 5YR 5/2 to Grayish red 5R 4/2
HLS-053	H2000/2109-19	fragment	MICRITIC	Grayish orange 10YR 7/4
HLS-054	H95/4962-27	fragment	MICRITIC	Grayish orange 10YR 7/4 with some black spots
HLS-055	H93/3892-82	drain cover?	MICRITIC	Pale yellowish brown 10 YR 6/2 to Grayish orange 10YR 7/4
HLS-056	H93/4051-12	fragment	sandy	Grayish Orange 10YR 7/4 (BANDED group)
HLS-057	H96/6251	fragment	MICRITIC	Grayish Orange 10YR 7/4 to Very pale orange 10YR 8/2
HLS-058	H94/3990-19	fragment	MICRITIC	Grayish Orange 10YR 7/4
HLS-060	H95/4719-1	fragment	MICRITIC	Dark yellowish orange 10YR 6/6 to Grayish Orange 10YR 7/4
HLS-061	H99/8394-20	fragment	MICRITIC	Grayish Orange 10YR 7/4
HLS-062	Vats (6098)	shaped stone	sandy	Very dusky purple 5RP 2/2 to GRAYish red purple 5RP 4/2
HLS-063	Vats (T#146)	shaped stone	sandy	Very dusky purple 5RP 2/2 to GRAYish red purple 5RP 4/2
HLS-064	Vats (T#141)	shaped stone	fine sandy	Brownish GRAY 5YR 4/1
HLS-065	T#130 (B-7)	shaped stone	sandy crystalline	GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2
HLS-066	H2001/11810-4	ringstone broken	sandy crystalline	GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2
HLS-067	Vats (T#140)	shaped stone	sandy crystalline	GRAYish purple 5P 4/2 to Grayish red purple 5RP 4/2
HLS-068	H98/8313-117	fragment	MICRITIC	Dark reddish brown 10R 3/4
HLS-069	H98/8306-126	ringstone frag.	fine sandy	Dark yellowish orange 10YR 6/6 (YELLOW group)
HLS-071	H99/8759-3	fragment	chalky	WHITE N9
HLS-072	H98/8603-41	fragment	chalky	WHITE N9
HLS-073	H2003-9904-16	fragment	chalky	WHITE N9
HLS-075	H2000/2748-13	fragment	chalky	WHITE N9

Appendix 11.1(cont.): Archaeological limestone samples from Harappa analyzed for this study. UPPERCASE indicates analysis type

sample #	artifact #	artifact type	texture	color
HLS-076	H2000/9846-20	fragment	chalky	WHITE N9
HLS-077	H2000/2763-28	fragment	chalky	WHITE N9
HLS-079	Vats (no #)	large cone	chalky	WHITE N9
HLS-080	Vats (no #)	large cone	chalky	WHITE N9
HLS-081	Vats (B1514)	bull sculpture frag.	fine sandy crystalline	Brownish GRAY 5YR 4/1
HLS-082	H2000/9880-75	shaped stone	fine sandy crystalline	GRAYish red purple 5RP 4/2
HLS-083	H99/9413-73	fragment	fine sandy	Moderate reddish brown 10R 4/6 (YELLOW group)
HLS-084	H99/8387-96	fragment	MICRITIC	Moderate yellowish brown 10YR 5/4
HLS-085	H99/8939-228	shaped stone	crystalline	Dark yellowish brown 10YR 4/2 (BANDED group)
HLS-086	H98/8331-69	fragment	fine sandy	GRAYish red 10R 4/2
HLS-087	H98/8307-2	shaped stone	fine sandy	Moderate reddish brown 10R 4/6 (GRAY group)
HLS-088	H98/8323-12	fragment	fine sandy	GRAYish red purple 5RP 4/2
HLS-089	H98/8324-11	shaped	fine sandy	GRAYish red purple 5RP 4/2
HLS-090	H98/8438-8	shaped stone	fine sandy crystalline	Brownish GRAY 5YR 4/1
HLS-091	H98/8321-1	Ringstone fragment	fine sandy crystalline	GRAYish red purple 5RP 4/2
HLS-093	Vats (T#121)	shaped stone	sandy crystalline	Dark reddish brown 10R 3/4 (GRAY group)
HLS-094	Vats (T#143)	shaped stone	fine sandy crystalline	GRAYish red 10R 4/2 to Pale reddish brown 10R 5/4
HLS-096	Vats (T#99)	shaped stone	fine sandy	Moderate reddish brown 10R 4/6 (GRAY group)
HLS-097	H98/8306-21	wavy ringstone frag.	fine sandy crystalline	Brownish GRAY 5YR 4/1
HLS-098	Vats (T#105)	shaped stone	fine sandy	Pale reddish brown 10R 5/4 (GRAY group)
HLS-099	Vats (T#142)	shaped stone	fine sandy crystalline	GRAY red purple 5RP 4/2
HLS-100	Vats (T#133)	shaped stone	fine sandy crystalline	Brownish GRAY 5YR 4/1

Appendix 11.1(cont.): Archaeological limestone samples from Harappa analyzed for this study. UPPERCASE indicates analysis type

sample #	artifact #	artifact type	texture	color
HLS-101	H98/8306-256	fragment	sandy crystalline	GRAYish red purple 5RP 4/2
HLS-102	H98/8306-23	shaped stone	fine sandy crystalline	Medium GRAY N5
HLS-103	H98/9724-50	fragment	sandy crystalline	Grayish red 10R 4/2 (BANDED group)
HLS-104	Vats (T#116)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-105	Vats T#123	shaped stone	sandy crystalline	Medium GRAY N5
HLS-106	Vats (T#124)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-107	Vats (T#125)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-108	Vats (T#126)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-109	Vats (T#128)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-110	Vats (T#134)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-111	Vats (T#136)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-112	Vats (T#138)	shaped stone	sandy crystalline	Medium GRAY N5
HLS-113	Vats (T#139)	shaped stone	sandy crystalline	Medium GRAY N5

Appendix 11.2: Results of ICP-MS analysis of the initial limestone set.
Elemental data in parts per million (ppm).

Sample	Ca	Sr	Ba	La	Ce
DLS-001	126265	111.97	17.37	11.133	19.082
DLS-002	157405	105.69	9.21	4.446	8.1
DLS-003	161388	115.74	22.57	10.248	11.392
DLS-004	99358	72	10.81	5.513	9.442
DLS-005	143223	172.17	2.57	7.791	11.947
DLS-006	133571	87.46	4.77	8.914	11.397
DLS-007	165081	109.55	14.22	12.909	16.916
DLS-008	194331	144.58	7.54	8.428	12.008
DLS-009	152483	148.9	17.15	15.346	23.635
DLS-010	174448	142.9	17.94	12.623	21.246
DLS-011	140829	119.04	10.03	9.405	15.091
DLS-012	129642	103.62	10.05	9.353	15.044
DLS-013	106197	93.09	16.27	25.333	40.449
DLS-014	158871	110.27	9.86	5.012	9.196
DLS-015	133821	102.24	4.77	5.654	7.965
JLS-001	115093	94.06	30.71	8.998	13.122
JLS-002	122255	59.73	12.32	2.566	5.343
JLS-003	127799	75.06	40.12	14.717	23.336
JLS-004	100394	57.25	23.75	12.64	22.023
JLS-005	104493	52.84	8.71	2.729	5.638
JLS-006	113054	31.39	13.85	2.641	5.521
JLS-007	111399	36.48	14.41	2.132	3.672
JLS-008	158288	50.41	22.13	3.14	6.747
JLS-009	134817	50.39	32.36	2.13	4.57
JLS-010	130113	37.68	19.87	4.837	8.714
JLS-011	161734	54.85	27.52	4.015	7.23
JLS-012	127905	62.45	14.29	3.529	6.058
JLS-013	126719	42.05	13.62	2.769	5.856
JLS-014	124329	47.82	10.47	1.97	3.84
JLS-015	114492	43.7	10.35	1.697	3.288
HLS-1	128037	123.43	6.22	11.757	20.015
HLS-2	162785	130.42	3.18	7.276	9.281
HLS-3	211961	282.91	1.16	3.589	6.5
HLS-4	140026	106.84	27.59	1.271	2.319
HLS-5	123213	85.05	14.29	8.217	10.153
HLS-6	114826	57.9	13.55	4.17	4.939

Appendix 11.3: Results of INAA analysis of the initial limestone set.
Elemental data in parts per million (ppm).

Sample	Al	Ca	Eu	Fe	La	Lu	Mg	Mn	Sr	V
DLS-001	2953	387460	1.33	34363	27.1	0.333	1375	1254	226.1	85.5
DLS-002	2343	408878	0.35	29846	9.7	0.099	838	477	165.6	22.7
DLS-003	6115	335005	1.68	115292	25.8	0.461	1828	837	111.7	84.2
DLS-004	2385	330933	1.11	72417	37.3	0.184	980	1447	137.3	96.2
DLS-005	1743	422005	0.49	11532	9.7	0.095	800	506	114	18.3
DLS-006	1613	412840	0.44	15918	8.9	0.095	538	500	60.4	13.7
DLS-007	1062	385372	0.30	8931	6.1	0.066	730	397	101.2	15.1
DLS-008	1515	386199	0.37	19605	8.1	0.087	603	458	158	18
DLS-009	1084	375720	0.32	12390	6.6	0.061	592	506	206.2	11.2
DLS-010	3706	375126	0.78	32575	12.8	0.149	713	511	85.4	43
DLS-011	1572	375008	0.31	8983	8.6	0.079	689	474	141.9	18.8
DLS-012	835	380274	0.32	29853	10.2	0.069	741	776	513.9	18.6
DLS-013	1484	371777	0.39	20953	9.2	0.087	641	434	140.2	16.3
DLS-014	947	388769	0.30	9908	8.9	0.059	623	388	207.2	12.3
DLS-015	1162	426359	0.27	10819	7.2	0.061	827	496	168.7	14
JLS-1	3784	342954	1.66	69959	31.0	0.399	1627	1197	442.8	103.1
JLS-2	3274	405748	0.60	11131	8.9	0.14	1000	633	593.1	62.3
JLS-3	1527	399216	0.77	14250	19.4	0.208	1509	885	552.4	23.5
JLS-4	13750	276295	0.78	10512	21.3	0.171	1430	1225	671.7	34.8
JLS-5	2659	379185	0.93	14376	19.0	0.215	1827	921	973.9	37.6
JLS-6	2008	410254	1.04	12230	23.9	0.246	958	691	363.4	28
JLS-7	2350	393629	1.04	12776	27.4	0.225	1057	691	317.9	26.6
JLS-8	1873	336543	0.60	12989	18.0	0.147	1184	644	412.8	13.6
JLS-9	4388	289262	1.47	49190	33.8	0.445	1347	1083	405.9	111.2
JLS-11	3584	311337	1.14	66718	26.6	0.347	1447	1129	381.6	87
JLS-12	3526	304023	1.15	53360	30.9	0.344	1528	924	444.2	80.1
JLS-13	3264	300605	1.20	81419	31.2	0.332	1094	1274	360	95.4
JLS-14	3627	317203	0.53	38173	8.5	0.213	1173	730	775.8	98.2
JLS-15	1794	350108	0.60	12216	16.7	0.129	1022	648	363.7	12.8
HLS-1	4119	344665	1.78	14462	7.1	0.071	1773	784	650.4	99.4
HLS-2	1811	396031	1.02	16654	7.7	0.088	1539	589	499.2	27.1
HLS-3	254	391304	0.85	178904	27.4	0.241	1128	285	738.8	307.2
HLS-4	1245	399206	0.06	14667	7.1	0.071	1101	563	313.2	15.7
HLS-5	1382	368002	0.61	11476	16.1	0.123	1572	623	213.9	22.7
HLS-6	1251	416175	0.49	10618	12.5	0.102	1165	682	159.3	13.3

Appendix 11.4: Results of ICP-AES analysis of the expanded geologic limestone sample set. *Elemental data in parts per million (ppm).*

sample#	Region	Location	Ca	Ba	Sr	Fe	Mg
DLS-001	Kutch/Khadir Island	Harappan quarry	331063	112.13	360	17894	2726
DLS-002	Kutch/Khadir Island	Harappan quarry	397579	283.45	244	7753	1962
DLS-003	Kutch/Khadir Island	Harappan quarry	367466	108.52	287	6714	1971
DLS-004	Kutch/Khadir Island	Harappan quarry	226195	50.21	168	4987	1195
DLS-005	Kutch/Khadir Island	Harappan quarry	353926	145.2	532	12601	2985
DLS-006	Kutch/Khadir Island	Harappan quarry	365226	20.57	269	7637	1831
DLS-007	Kutch/Khadir Island	Harappan quarry	367289	117.81	276	7611	1913
DLS-008	Kutch/Khadir Island	Harappan quarry	390535	98.91	323	8403	2034
DLS-009	Kutch/Khadir Island	Harappan quarry	277943	152.26	272	22480	2544
DLS-010	Kutch/Khadir Island	Harappan quarry	351698	63.38	312	8230	3493
DLS-011	Kutch/Khadir Island	Harappan quarry	337063	37.82	310	15197	2427
DLS-012	Kutch/Khadir Island	Harappan quarry	336488	49.62	311	10661	2502
DLS-013	Kutch/Khadir Island	Harappan quarry	379955	44.2	361	14142	2911
DLS-014	Kutch/Khadir Island	Harappan quarry	359622	40.87	242	25333	2259
DLS-015	Kutch/Khadir Island	Harappan quarry	415959	28.04	348	8111	2205
DLS-016	Kutch/Khadir Island	Harappan quarry	434542	41.27	300	4813	2623
DLS-017	Kutch/Khadir Island	Harappan quarry	463583	37.95	377	6323	3332
DLS-018	Kutch/Khadir Island	Harappan quarry	299004	143.82	500	23211	3162
DLS-019	Kutch/Khadir Island	Harappan quarry	462375	30.16	360	8223	3060
DLS-020	Kutch/Khadir Island	Harappan quarry	441406	26.83	354	8192	3087
DLS-021	Kutch/Khadir Island	Harappan quarry	448342	22.67	344	8070	3074
DLS-022	Kutch/Khadir Island	Harappan quarry	407298	133.77	298	15167	3363
DLS-023	Kutch/Khadir Island	Harappan quarry	428826	29.34	299	27596	2596
DLS-024	Kutch/Khadir Island	Harappan quarry	410185	26.42	378	11325	2849
DLS-025	Kutch/Khadir Island	Harappan quarry	352952	37.39	287	8285	2489
DLS-026	Kutch/Khadir Island	Harappan quarry	387533	57.5	262	7264	2382
DLS-027	Kutch/Khadir Island	Harappan quarry	374897	29.57	393	14845	5600
DLS-028	Kutch/Khadir Island	Harappan quarry	276460	44.4	201	2436	1682
DLS-029	Kutch/Khadir Island	Harappan quarry	275510	18.45	243	1785	2504
DLS-030	Kutch/Khadir Island	Harappan quarry	259520	21.69	230	1748	1971
LTH-001	Kutch/Khadir Island	Limdiwali Tari	341565	13.26	264	2217	1867
LTH-002	Kutch/Khadir Island	Limdiwali Tari	332137	37.03	313	1550	2141
LTH-003	Kutch/Khadir Island	Limdiwali Tari	313953	41.56	225	1207	1645
LTH-004	Kutch/Khadir Island	Limdiwali Tari	328832	58.41	270	1367	2110
LTH-005	Kutch/Khadir Island	Limdiwali Tari	341857	23.9	264	2835	2180
LTH-006	Kutch/Khadir Island	Limdiwali Tari	319302	56.21	399	1906	1999

Appendix 11.4 (cont.): Results of ICP-AES analysis of the expanded geologic limestone sample set. *Elemental data in parts per million (ppm).*

sample#	Region	Location	Ca	Ba	Sr	Fe	Mg
LTH-007	Kutch/Khadir Island	Limdiwali Tari	305745	29.39	245	1654	1985
LTH-008	Kutch/Khadir Island	Limdiwali Tari	317857	34.49	258	2223	1827
LTH-009	Kutch/Khadir Island	Limdiwali Tari	301952	118	241	1183	1262
LTH-010	Kutch/Khadir Island	Limdiwali Tari	310043	18.19	247	1494	1915
LTH-011	Kutch/Khadir Island	Limdiwali Tari	318406	105	255	1314	1487
LTH-012	Kutch/Khadir Island	Limdiwali Tari	316330	38.11	277	1555	2025
LTH-013	Kutch/Khadir Island	Limdiwali Tari	310133	28.79	241	1908	1696
LTH-014	Kutch/Khadir Island	Limdiwali Tari	299548	50.96	233	1919	1841
LTH-015	Kutch/Khadir Island	Limdiwali Tari	321422	57.56	391	1836	2027
P-001	Kutch/Pachchham I.	near Juni Kuran	268205	35.22	337	2864	2466
P-002	Kutch/Pachchham I.	near Juni Kuran	224788	35.53	263	2904	1674
P-003	Kutch/Pachchham I.	near Juni Kuran	330452	3.53	354	2205	1476
P-004	Kutch/Pachchham I.	near Juni Kuran	318651	7.23	343	1226	1401
P-005	Kutch/Pachchham I.	near Juni Kuran	303873	18.25	271	1296	1309
P-006	Kutch/Pachchham I.	near Juni Kuran	333266	6.18	341	1409	1392
P-007	Kutch/Pachchham I.	near Juni Kuran	240965	127	323	2778	36712
P-008	Kutch/Pachchham I.	near Juni Kuran	316300	41.45	293	1454	1542
P-009	Kutch/Pachchham I.	near Juni Kuran	309071	180	404	2448	2067
P-010	Kutch/Pachchham I.	near Juni Kuran	283928	53.86	285	1475	1418
P-011	Kutch/Pachchham I.	near Juni Kuran	267741	11.99	446	4733	1760
P-012	Kutch/Pachchham I.	near Juni Kuran	207755	10.99	261	3129	1271
P-013	Kutch/Pachchham I.	near Juni Kuran	300556	66.75	245	12203	1602
P-014	Kutch/Pachchham I.	near Juni Kuran	199705	10.85	329	4454	1526
P-015	Kutch/Pachchham I.	near Juni Kuran	133109	6.57	97	1871	658
P-016	Kutch/Pachchham I.	near Juni Kuran	135284	13.75	226	2718	927
P-017	Kutch/Pachchham I.	near Juni Kuran	133096	5.95	178	5115	1278
P-018	Kutch/Pachchham I.	near Juni Kuran	233959	23.49	200	12019	1946
P-019	Kutch/Pachchham I.	near Juni Kuran	187688	12.33	218	3294	1276
P-020	Kutch/Pachchham I.	near Juni Kuran	125505	16.02	206	1921	979
JLS-001	Rajasthan-Jaisalmer	Mool Sagar Khan	389975	319	316	10946	2503
JLS-002	Rajasthan-Jaisalmer	Jethway	414757	33.63	262	6327	1794
JLS-003	Rajasthan-Jaisalmer	Mool Sagar Khan	338291	131	241	15292	2486
JLS-004	Rajasthan-Jaisalmer	Mool Sagar Khan	309427	59.57	239	13406	1659
JLS-005	Rajasthan-Jaisalmer	Jethway	376232	19.86	208	3827	1400
JLS-006	Rajasthan-Jaisalmer	Jethway	405651	24.06	127	2981	935
JLS-007	Rajasthan-Jaisalmer	Jethway	386713	58.17	141	3606	1061

Appendix 11.4 (cont.): Results of ICP-AES analysis of the expanded geologic limestone sample set. *Elemental data in parts per million (ppm).*

sample#	Region	Location	Ca	Ba	Sr	Fe	Mg
JLS-008	Rajasthan-Jaisalmer	Jethway	359132	71.78	135	3316	955
JLS-009	Rajasthan-Jaisalmer	Jethway	359295	128.9	155	3222	1024
JLS-010	Rajasthan-Jaisalmer	Mool Sagar Khan	332607	62.93	105	5300	979
JLS-011	Rajasthan-Jaisalmer	Mool Sagar Khan	387637	50.90	151	3345	1190
JLS-012	Rajasthan-Jaisalmer	Mool Sagar Khan	367296	27.97	198	3649	1623
JLS-013	Rajasthan-Jaisalmer	Jethway	374355	27.64	135	3439	955
JLS-014	Rajasthan-Jaisalmer	Jethway	354914	43.08	150	3901	943
JLS-015	Rajasthan-Jaisalmer	Jethway	383276	17.98	164	4437	1012
JLS-016	Rajasthan-Jaisalmer	Jethway	417839	158.6	243	4353	2086
JLS-017	Rajasthan-Jaisalmer	Jethway	464355	76.82	190	3566	2016
JLS-018	Rajasthan-Jaisalmer	Jethway	515504	20.29	281	3148	2163
JLS-019	Rajasthan-Jaisalmer	Jethway	462682	96.23	208	3483	2814
JLS-020	Rajasthan-Jaisalmer	Jethway	277235	85.01	152	1140	1468
JLS-021	Rajasthan-Jaisalmer	Jethway	284176	47.59	117	729	1161
JLS-022	Rajasthan-Jaisalmer	Jethway	303138	24.64	134	665	1143
JLS-023	Rajasthan-Jaisalmer	Habur	271288	66.41	129	630	1146
JLS-024	Rajasthan-Jaisalmer	Habur	280923	38.85	167	932	1283
JLS-025	Rajasthan-Jaisalmer	Habur	314692	43.75	199	2709	1727
JLS-026	Rajasthan-Jaisalmer	Habur	276003	30.13	142	786	1329
JLS-027	Rajasthan-Jaisalmer	Habur	220158	32.10	127	647	1076
JLS-028	Rajasthan-Jaisalmer	Habur	279734	27.42	148	1177	1310
JLS-029	Rajasthan-Jaisalmer	Habur	258038	29.78	150	3109	1234
JLS-030	Rajasthan-Jaisalmer	Habur	371593	31.40	151	2788	1071
JLS-031	Rajasthan-Jaisalmer	Habur	273143	59.61	197	2147	1516
JLS-032	Rajasthan-Jaisalmer	Habur	346034	40.67	152	1133	996
JLS-033	Rajasthan-Jaisalmer	Habur	296821	39.86	191	1005	1410
JLS-034	Rajasthan-Jaisalmer	Habur	338900	79.17	231	1731	1615
JLS-035	Rajasthan-Jaisalmer	Habur	348362	32.21	107	788	868
JLS-036	Rajasthan-Jaisalmer	Mool Sagar Khan	308686	64.13	146	1019	1287
JLS-037	Rajasthan-Jaisalmer	Mool Sagar Khan	340784	37.42	127	826	948
JLS-038	Rajasthan-Jaisalmer	Mool Sagar Khan	140094	77.9	104	694	622
JLS-039	Rajasthan-Jaisalmer	Mool Sagar Khan	337400	20.66	103	730	855
JLS-040	Rajasthan-Jaisalmer	Mool Sagar Khan	296738	31.69	96	880	1194
JLS-041	Rajasthan-Jaisalmer	Jethway	337982	61.65	219	2024	1631
JLS-042	Rajasthan-Jaisalmer	Jethway	347986	42.89	153	1139	996
JLS-043	Rajasthan-Jaisalmer	Jethway	361109	27.27	158	1155	1069

Appendix 11.4 (cont.): Results of ICP-AES analysis of the expanded geologic limestone sample set. *Elemental data in parts per million (ppm).*

sample#	Region	Location	Ca	Ba	Sr	Fe	Mg
JLS-044	Rajasthan-Jaisalmer	Habur	340108	28.28	209	1196	1441
JLS-045	Rajasthan-Jaisalmer	Habur	344640	21.11	146	1114	1003
JLS-046	Rajasthan-Jaisalmer	Habur	350774	20.56	148	1136	1022
JLS-047	Rajasthan-Jaisalmer	Habur	323617	36.96	120	834	885
JLS-048	Rajasthan-Jaisalmer	Habur	330826	48.30	154	1077	1157
JLS-049	Rajasthan-Jaisalmer	Habur	343405	11.19	192	745	1297
JLS-050	Rajasthan-Jaisalmer	Habur	319604	73.75	234	2245	1819
JLS-051	Rajasthan-Jaisalmer	Amar Sagar	208001	107.12	202	1003	1526
JLS-052	Rajasthan-Jaisalmer	Amar Sagar	348387	33.19	130	886	951
JLS-053	Rajasthan-Jaisalmer	Amar Sagar	318835	33.13	135	970	992
JLS-054	Rajasthan-Jaisalmer	Amar Sagar	290826	37.75	112	941	1220
JLS-055	Rajasthan-Jaisalmer	Amar Sagar	306224	46.43	182	1552	1448
JLS-056	Rajasthan-Jaisalmer	Amar Sagar	309604	37.19	194	1042	1512
JLS-057	Rajasthan-Jaisalmer	Amar Sagar	321373	30.57	167	1056	1144
JLS-058	Rajasthan-Jaisalmer	Amar Sagar	331589	48.96	219	1705	1744
JLS-059	Rajasthan-Jaisalmer	Amar Sagar	334251	38.44	189	1237	1362
JLS-060	Rajasthan-Jaisalmer	Amar Sagar	474903	46.64	190	2762	1763
RHLS-001	Sindh - Rohri Hills	Nara near Thari	487384	60.82	691	320	2125
RHLS-002	Sindh - Rohri Hills	Nara near Thari	519208	29.14	925	524	2366
RHLS-003	Sindh - Rohri Hills	Kandarki	500046	27.45	870	341	1622
RHLS-004	Sindh - Rohri Hills	Adam Sultan	493414	30.81	1540	873	2265
RHLS-005	Sindh - Rohri Hills	Adam Sultan	452711	23.79	2074	1053	6753
RHLS-006	Sindh - Rohri Hills	Rohri	507840	23.01	746	334	1713
RHLS-007	Sindh - Rohri Hills	Rohri	499546	21.32	597	4468	1451
RHLS-008	Sindh - Rohri Hills	Kot Diji	493205	36.77	984	730	1946
RHLS-009	Sindh - Rohri Hills	Kot Diji	512351	62.04	1270	906	1965
RHLS-010	Sindh - Rohri Hills	Kot Diji	538777	46.84	1447	834	2510
RHLS-011	Sindh - Rohri Hills	Kot Diji	522827	36.52	1282	686	2437
RHLS-012	Sindh - Rohri Hills	Kot Diji	479314	40.9	1363	767	3787
RHLS-013	Sindh - Rohri Hills	Kot Diji	486996	28.03	1707	769	2200
RHLS-014	Sindh - Rohri Hills	Kot Diji	506259	41.62	1251	545	1737
RHLS-015	Sindh - Rohri Hills	Kot Diji	502324	36.76	654	749	1642
RHLS-016	Sindh - Rohri Hills	Kot Diji	495404	36.62	618	487	1548
RHLS-017	Sindh - Rohri Hills	Adam Sultan	451690	22.28	1968	913	6821
RHLS-018	Sindh - Rohri Hills	Nara near Thari	509239	27.13	865	567	2342
RHLS-019	Sindh - Rohri Hills	Kot Diji	506344	50.86	769	629	1676

Appendix 11.4 (cont.): Results of ICP-AES analysis of the expanded geologic limestone sample set. *Elemental data in parts per million (ppm).*

sample#	Region	Location	Ca	Ba	Sr	Fe	Mg
RHLS-020	Sindh - Rohri Hills	Kot Diji	498539	57.28	1695	557	2039
RHLS-021	Sindh - Rohri Hills	Kot Diji	475943	45.82	1825	1214	2649
RHLS-022	Sindh - Rohri Hills	Kot Diji	509014	31.26	1203	521	2269
RHLS-023	Sindh - Rohri Hills	Kot Diji	491319	34.70	978	571	1723
RHLS-024	Sindh - Rohri Hills	Kot Diji	488056	39.32	1215	865	2242
RHLS-025	Sindh - Rohri Hills	Kot Diji	493299	75.23	1449	596	2111
GJLS-1	Gujarat - Junagadh	Adityana	486320	53.60	2214	1996	5618
GJLS-2	Gujarat - Junagadh	Adityana	427030	76.03	857	2799	4893
GJLS-3	Gujarat - Junagadh	Adityana	431957	103.49	1928	4502	7307
GJLS-4	Gujarat - Junagadh	Adityana	416530	75.67	1028	3389	5449
GJLS-5	Gujarat - Junagadh	Adityana	464294	114.38	2754	3892	7937
LPLS-1	Balochistan - Loralai	Loralai Town	423434	80.54	886	1252	1909
LPLS-2	Balochistan - Loralai	Loralai Town	452280	80.01	957	1094	1734
LPLS-3	Balochistan - Loralai	Loralai Town	502506	90.63	1096	1241	1913
KRLS-001	Sindh - Kirthar	Ranikot	455785	334.21	679	8764	2867
KRLS-002	Sindh - Kirthar	Ranikot	446144	619.91	631	7162	2547

Appendix 11.5: Results of ICP-AES analysis of the expanded Harappan limestone sample set. Elemental data in parts per million (ppm). MSK = Mool Sagar Khan (Jaisalmer Formation)

sample#	Mound	Trench	Period	Probable geologic provenience	Ca	Ba	Sr	Fe	Mg
HLS-001	AB-E	53	3+	Pachchham Fm. – Khadir quarry	357994	16.91	400.1	23213	2541
HLS-002	n/a	n/a	n/a	Pachchham Fm. – Juni Kuran	379903	7.59	335	7285	2099
HLS-003	E	54	3+	Unclear at this time * not Rohri Hills	398604	0.01	600.4	773	1177
HLS-004	E	56	3+	Pachchham Fm. – Khadir quarry	406386	139.78	353.1	7384	2098
HLS-005	E	54	3+	Pachchham Fm. – Khadir * possibly MSK	373805	88.14	296.2	8190	2231
HLS-006	AB	31	3+	Pachchham Fm. – Khadir quarry	405231	34.94	273.8	9520	1784
HLS-007	n/a	n/a	n/a	Pachchham Fm. – Khadir quarry	403443	33.5	366.1	9868	3585
HLS-008	ET	Thana	n/a	Pachchham Fm. – Khadir quarry	455098	30.71	376.6	8306	3035
HLS-009	E	36	3C	Sindh – Rohri Hills	522709	29.77	668.8	635	2068
HLS-010	E	46	3C	Sindh – Rohri Hills	536330	119.5	255.7	407	2345
HLS-011	ET	surf	3+	Pachchham Fm. – Khadir quarry	471586	30.01	337.9	6470	2722
HLS-012	E	7	3+	Pachchham Fm. – Khadir quarry	430884	24.95	381.1	7914	3381
HLS-013	E	8	3C	Pachchham Fm. – Khadir quarry	458575	29.32	344.2	8126	2745
HLS-014	E	8	3C	Pachchham Fm. – Khadir quarry	466838	25.84	336.1	6934	3170
HLS-015	AB	mosque	3+	Pachchham Fm. – Khadir * possibly MSK	502028	29.49	318	4894	2614
HLS-016	E	7_8	3C	Pachchham Fm. – Khadir quarry	469517	33.91	427.2	8303	3965
HLS-017	ET	28	3C	Pachchham Fm. – Juni Kuran	475755	52.13	450.5	5945	2931
HLS-018	E	7_8	3+	Pachchham Fm. – Khadir quarry	433480	39.56	318.6	16011	3311
HLS-019	E	7_8	3+	Pachchham Fm. – Khadir quarry	436903	163.6	344.1	8640	3280
HLS-020	E	7_8	3C	Jaisalmer Fm. – Mool Sagar Khan	481506	94.33	302.4	7358	2440
HLS-021	AB	31	3C	Pachchham Fm. – Khadir quarry	437755	46.3	329.3	7861	2816
HLS-022	E	36	3+	Pachchham Fm. – Juni Kuran	455274	36.98	516.1	7217	4976
HLS-023	F	37	3+	Jaisalmer Fm. – Mool Sagar Khan	419655	105.34	292.3	7727	2588
HLS-024	AB	39	3+	Pachchham Fm. – Khadir * possibly MSK	294439	33.41	199.3	3960	1892

Appendix 11.5 (cont.): Results of ICP-AES analysis of the expanded Harappan limestone sample set. Elemental data in parts per million (ppm). MSK = Mool Sagar Khan (Jaisalmer Formation)

sample#	Mound	Trench	Period	Probable geologic provenience	Ca	Ba	Sr	Fe	Mg
HLS-025	AB	39	3+	Pachchham Fm. – Khadir quarry	495416	58.79	388.8	7411	2438
HLS-026	AB	39	3C	Pachchham Fm. – Limdiwali Tari	489313	31.27	372.7	4957	2606
HLS-027	AB	39	3C	Pachchham Fm. – Khadir quarry	509927	23.13	341.5	6270	2996
HLS-028	AB	39	3C	Pachchham Fm. – Juni Kuran	477468	24.12	363	4559	2596
HLS-029	AB	39	3C	Pachchham Fm. – Khadir quarry	418869	49.56	524.4	13356	3401
HLS-030	AB	39	3+	Pachchham Fm. – Khadir quarry	493072	49.68	368.9	9005	2944
HLS-031	AB	39	3C	Pachchham Fm. – Khadir quarry	426012	62.91	370.8	13621	3087
HLS-032	AB	39	3C	Pachchham Fm. – Khadir quarry	432848	29.21	310.5	6001	2539
HLS-033	AB	39	3+	Pachchham Fm. – Khadir quarry	449283	21.94	299.4	4610	2615
HLS-034	AB	39	3C	Pachchham Fm. – Khadir quarry	411862	23.31	307.6	7671	3188
HLS-035	AB	39	3+	Pachchham Fm. – Juni Kuran	462867	55.6	462.7	6686	2428
HLS-036	AB	39	3+	Pachchham Fm. – Khadir quarry	419103	29.07	404.5	8677	4373
HLS-037	F	43	3C	Pachchham Fm. – Khadir quarry	409903	34.95	353	14722	3562
HLS-038	F	43	3C	Pachchham Fm. – Khadir * possibly MSK	455116	25.57	294.6	5114	2532
HLS-039	E	54	3+	Jaisalmer Fm. – Mool Sagar Khan	491088	75.53	333.8	6808	2670
HLS-040	E	56	3+	Pachchham Fm. – Khadir quarry	429730	60.62	309.6	11222	2629
HLS-041	AB	B	3C+	Pachchham Fm. – Khadir * possibly MSK	490547	28.21	330.6	7478	2958
HLS-042	AB	B	3C+	Pachchham Fm. – Khadir * possibly MSK	379237	36.78	258.8	4079	2304
HLS-043	AB	B	3C+	Jaisalmer Fm. – Mool Sagar Khan	449342	53.06	259.9	7175	2455
HLS-044	AB	B	3C+	Pachchham Fm. – Khadir * possibly MSK	460706	136.71	386.5	6080	2930
HLS-045	AB	B	3C+	Pachchham Fm. – Khadir quarry	499251	24.02	365.4	5328	2922
HLS-046	AB	B	3C+	Jaisalmer Fm. – Mool Sagar Khan	497680	283.14	435.5	5755	3343
HLS-047	AB	B	3C+	Jaisalmer Fm. – Mool Sagar Khan	454710	147.01	347	7952	3380
HLS-048	AB	39	3+	Jaisalmer Fm. – Mool Sagar Khan	470980	168.86	267.6	10698	2480

Appendix 11.5 (cont.): Results of ICP-AES analysis of the expanded Harappan limestone sample set. Elemental data in parts per million (ppm). MSK = Mool Sagar Khan (Jaisalmer Formation)									
sample#	**Mound**	**Trench**	**Period**	**Probable geologic provenience**	**Ca**	**Ba**	**Sr**	**Fe**	**Mg**
HLS-049	AB	38	3+	Pachchham Fm. – Khadir * possibly MSK	489322	54.49	471.8	10000	3130
HLS-050	AB	39	3+	Pachchham Fm. – Khadir quarry	467789	51.62	431.6	7392	2739
HLS-051	AB	39	3+	Pachchham Fm. – Khadir quarry	519683	248.09	584.6	4485	1885
HLS-052	E	54	3+	Unclear at this time * not Rohri Hills	542850	268.41	565.6	1639	1773
HLS-053	E	54	3+	Unclear at this time * not Rohri Hills	540505	26.7	663	749	2107
HLS-054	ET	28	3+	Sindh – Rohri Hills	12058.4	141.01	62.5	2785	747
HLS-055	E	8	3C	Unclear at this time * not Rohri Hills	491707	30.58	578.2	1890	6025
HLS-056	ET	10W	3+	Pachchham Fm. – Juni Kuran	514765	101.62	622.4	865	2230
HLS-057	E	36	3+	Sindh – Rohri Hills	527199	66.14	481.4	1157	1777
HLS-058	E	7_8	3C	Sindh – Rohri Hills	54114.8	171.38	108.2	589	732
HLS-060	ET	19W	3C	Sindh – Rohri Hills	529073	173.03	778.9	476	2123
HLS-061	AB	39	3+	Sindh – Rohri Hills	262116	43.52	375.6	400	1076
HLS-062	AB	B	3C+	Pachchham Fm. – Juni Kuran	482366	66.02	643.7	8119	3906
HLS-063	AB	B	3C+	Pachchham Fm. – Juni Kuran	483640	105.46	734.6	8454	4397
HLS-064	AB	B	3C+	Pachchham Fm. – Khadir quarry	454805	43.39	402	10315	3249
HLS-065	AB	B	3C+	Pachchham Fm. – Juni Kuran	494695	38.9	539.7	7560	4804
HLS-066	E	11	3C	Pachchham Fm. – Juni Kuran	527899	193.84	968.2	9021	4597
HLS-067	AB	B	3C+	Pachchham Fm. – Juni Kuran	534131	36.48	869.1	7237	3978
HLS-068	AB	39	3+	Unclear at this time * not Rohri Hills	152550	138.23	492.7	47100	5491
HLS-069	AB	39	3+	Pachchham Fm. – Khadir quarry	526037	30.59	381.4	6143	3131
HLS-071	F	43	3C	Unclear * possibly Rohri Hills or Parh Fm.	557303	60.45	1305	447	2686
HLS-072	F	43	3+	Unclear * possibly Rohri Hills or Parh Fm.	510501	32.98	1210.7	262	4577
HLS-073	n/a	n/a	3C+	Unclear * possibly Rohri Hills or Parh Fm.	493182	30.71	572.4	294	2191
HLS-075	E	55	3C	Unclear * possibly Rohri Hills or Parh Fm.	554604	53.8	1180.9	192	2778

Appendix 11.5 (cont.): Results of ICP-AES analysis of the expanded Harappan limestone sample set. Elemental data in parts per million (ppm). MSK = Mool Sagar Khan (Jaisalmer Formation)

sample#	Mound	Trench	Period	Probable geologic provenience	Ca	Ba	Sr	Fe	Mg
HLS-076	E	43	3C	Unclear * possibly Rohri Hills or Parh Fm.	498653	30.81	1839.4	300	3332
HLS-077	E	55	3C	Unclear * possibly Rohri Hills or Parh Fm.	502045	61.41	1217.6	217	2585
HLS-079	AB	Vats III & IV	3C+	Unclear * possibly Rohri Hills or Parh Fm.	417142	32.67	422.1	306	1749
HLS-080	AB	Vats III & IV	3C+	Unclear * possibly Rohri Hills or Parh Fm.	518853	46.43	556.3	397	2229
HLS-081	AB	B	3C+	Pachchham Fm. – Khadir * *possibly not*	445348	44.44	471.1	13837	19884
HLS-082	E	43	3C	Pachchham Fm. – Juni Kuran	476886	42.8	483	4875	5415
HLS-083	AB	39	3+	Pachchham Fm. – Khadir * possibly MSK	487541	51.92	319.9	10566	2655
HLS-084	AB	39	3+	Unclear at this time * not Rohri Hills	7965.74	81.28	38.8	5574	836
HLS-085	AB	39	3+	Pachchham Fm. – Juni Kuran	488421	32.83	495.5	7686	3282
HLS-086	AB	39	3+	Pachchham Fm. – Juni Kuran	514209	32.09	826.8	9036	4441
HLS-087	AB	39	3C	Pachchham Fm. – Khadir quarry	439958	217.85	338.9	10937	3114
HLS-088	AB	39	3C	Pachchham Fm. – Juni Kuran	458675	39.1	738.5	7308	3816
HLS-089	AB	39	3C	Pachchham Fm. – Juni Kuran	445316	41.13	788.2	12129	4833
HLS-090	AB	39	3+	Pachchham Fm. – Juni Kuran	506587	32.06	761.5	8886	4521
HLS-091	AB	39	3+	Pachchham Fm. – Juni Kuran	493961	38.02	664.1	8327	4275
HLS-093	AB	B	3C+	Pachchham Fm. – Juni Kuran	369045	45.71	415.7	5582	2555
HLS-094	AB	B	3C+	Pachchham Fm. – Khadir * possibly JK	489640	54.93	452.5	6579	3084
HLS-096	AB	B	3C+	Pachchham Fm. – Juni Kuran	488596	80.25	514.1	10877	3686
HLS-097	AB	39	3+	Pachchham Fm. – Khadir * possibly JK	476179	83.25	550	10686	4537
HLS-098	AB	B	3C+	Pachchham Fm. – Khadir * possibly JK	475619	53.55	295.3	5037	3147
HLS-099	AB	B	3C+	Jaisalmer Fm. – Mool Sagar Khan	469359	55.42	647.4	9283	4075
HLS-100	AB	B	3C+	Pachchham Fm. – Juni Kuran	477057	38.56	802	9060	4308

Appendix 11.5 (cont.): Results of ICP-AES analysis of the expanded Harappan limestone sample set. Elemental data in parts per million (ppm). MSK = Mool Sagar Khan (Jaisalmer Formation)									
sample#	**Mound**	**Trench**	**Period**	**Probable geologic provenience**	**Ca**	**Ba**	**Sr**	**Fe**	**Mg**
HLS-101	AB	39	3+	Pachchham Fm. – Juni Kuran	438168	36.1	663.5	10465	4741
HLS-102	AB	39	3+	Pachchham Fm. – Juni Kuran	443389	33.68	583.9	9103	4079
HLS-103	F	43	3C	Pachchham Fm. – Juni Kuran	452980	37.38	776.9	6697	3640
HLS-104	AB	B	3C+	Pachchham Fm. – Khadir * *possibly not*	305759	9.42	334.5	9873	11071
HLS-105	AB	B	3C+	Pachchham Fm. – Juni Kuran	318474	11.54	518.6	7435	4579
HLS-106	AB	B	3C+	Pachchham Fm. – Juni Kuran	317632	14.38	506.6	6883	4099
HLS-107	AB	B	3C+	Pachchham Fm. – Juni Kuran	322710	9.13	771.7	5249	3115
HLS-108	AB	B	3C+	Pachchham Fm. – Juni Kuran	316082	10.15	526.5	5629	2608
HLS-109	AB	B	3C+	Pachchham Fm. – Juni Kuran	301710	11.63	652.8	4694	2952
HLS-110	AB	B	3C+	Pachchham Fm. – Juni Kuran	244254	9.85	396.2	4157	2261
HLS-111	AB	B	3C+	Pachchham Fm. – Juni Kuran	297134	8.46	458.6	5285	2614
HLS-112	AB	B	3C+	Pachchham Fm. – Juni Kuran	322926	13.43	395.9	7221	3500
HLS-113	AB	B	3C+	Pachchham Fm. – Juni Kuran	309994	52.55	575.7	5403	4153

Appendix 11.6: Standardized canonical discriminant function coefficients for figures in Chapter 11 generated using canonical discriminant analysis

Figure 11.13

	Function 1	Function 2
Log(Sr/Ca)	0.538854	-0.263662
Log(Ba/Ca)	-0.515918	0.632779
Log(La/Ca)	2.049668	1.390571
Log(Ce/Ca)	-1.504577	-0.910055

Figure 11.14

	Function 1	Function 2
Log Al	-0.056874	0.749801
Log Ca	-0.576539	0.134206
Log Eu	0.122040	-0.401635
Log Fe	-1.077745	0.440063
Log La	0.218032	0.290513
Log Lu	2.207798	-1.296973
Log Mg	-0.587172	1.065233
Log Mn	-0.632225	0.721394
Log Sr	1.218172	-0.332209
Log V	-0.437484	-0.647896

Figure 11.16

	Function 1	Function 2
Log(Sr/Ca)	0.073614	0.464596
Log(Ba/Ca)	0.211263	-1.461557
Log(La/Ca)	0.650717	0.909790
Log(Ce/Ca)	0.211846	0.326597

Figures 11.19, 11.20, 11.21, 11.23, 11.26, & 11.28

	Function 1	Function 2
Log(Ba/Ca)	-0.058470	-0.342616
Log(Sr/Ca)	1.135848	0.240759
Log(Mg/Ca)	-0.467101	0.446292
Log(Fe/Ca)	-0.469716	0.689877

Figure 11.25

	Function 1
Log(Sr/Ca)	0.844995
Log(Mg/Ca)	0.610469
Log(Fe/Ca)	0.420370
Log(Ba/Ca)	-0.209630

Figure 11.22

	Function 1	Function 2
Log(Ba/Ca)	-0.364807	0.084021
Log(Sr/Ca)	0.907554	-0.696177
Log(Mg/Ca)	0.098317	0.238141
Log(Fe/Ca)	0.188085	1.045765

Figures 11.24 & 11.27

	Function 1	Function 2
Log(Ba/Ca)	-0.438160	-0.066719
Log(Sr/Ca)	1.000905	-0.440645
Log(Mg/Ca)	0.139384	0.083884
Log(Fe/Ca)	-0.054452	1.106942

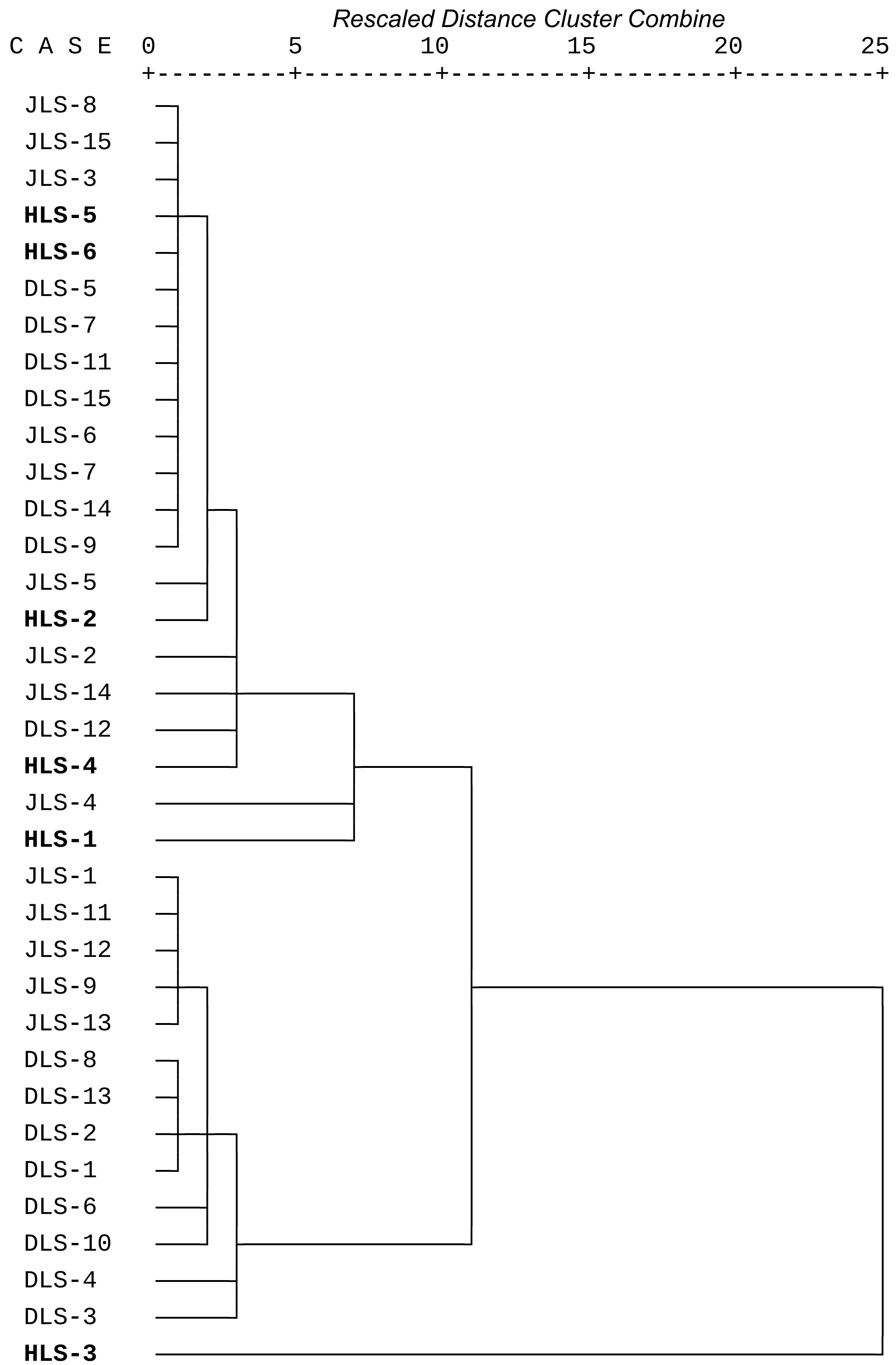
Figure 11.29

	Function 1	Function 2
Log(Ba/Ca)	0.319044	0.637698
Log(Sr/Ca)	0.255953	0.084343
Log(Mg/Ca)	0.192665	-0.852032
Log(Fe/Ca)	0.703255	0.367320

Figure 11.30

	Function 1	Function 2
Log(Ba/Ca)	-0.031867	-0.290917
Log(Sr/Ca)	1.136319	0.170960
Log(Mg/Ca)	-0.422515	0.540320
Log(Fe/Ca)	-0.443741	0.658560

Appendix 11.7: Hierarchical cluster analysis of initial limestone samples set INAA data. Dendrogram generated using median clustering and Pearson correlation.



Appendix 12.1: Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	*reference*	*sample*	**208/207**	**207/206**	**207/204**
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch1	2.4816	0.8439	15.604
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch1.2	2.4820	0.8433	15.635
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch2	2.4756	0.8418	15.636
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch2.2	2.4807	0.8417	15.639
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch3	2.4817	0.8435	15.633
Balochistan - Chagai (Koh-i-Sultan)	LARCH	ch3.2	2.4854	0.8412	15.640
Balochistan - Chagai (Rekodiq)	LARCH	ch4	2.4856	0.8362	15.665
Balochistan - Chagai (Rekodiq)	LARCH	ch4.2	2.4872	0.8366	15.655
Balochistan - Chagai (Rekodiq)	LARCH	ch5	2.4833	0.8374	15.660
Balochistan - Chagai (Rekodiq)	LARCH	ch5.2	2.4857	0.8375	15.713
Balochistan - Chagai (Rekodiq)	LARCH	ch6	2.4847	0.8367	15.689
Balochistan - Chagai (Rekodiq)	LARCH	ch6.2	2.4849	0.8355	15.634
Balochistan - Khuzdar (Gunga)	LARCH	KHZ1	2.4578	0.8450	15.614
Balochistan - Khuzdar (Gunga)	LARCH	KHZ2	2.4499	0.8493	15.607
Balochistan - Khuzdar (Gunga)	Siddiqui 1994: Table 7.4	SGL-101	2.4693	0.8459	15.733
Balochistan - Khuzdar (Gunga)	Siddiqui 1994: Table 7.4	SGL-102	2.4697	0.8461	15.721
Balochistan - Khuzdar (Gunga)	Siddiqui 1994: Table 7.4	SGL-103	2.4656	0.8447	15.646
Balochistan - Las Bela - Kanrach Valley (Kharrari)	Bhutta 1992: Table 3	AB258	2.4630	0.8500	15.703
Balochistan - Las Bela - Kanrach Valley (Duddar)	Bhutta 1992: Table 3	AB269	2.4667	0.8497	15.699
Balochistan - Las Bela - Kanrach Valley (Kharrari)	Bhutta 1992: Table 3	AB295	2.4643	0.8489	15.694

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	3P-9	2.4619	0.8482	15.704
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	3P9B	2.4612	0.8472	15.692
Balochistan - Las Bela - Kanrach Valley (Bamph)	LARCH	hppb9	2.4588	0.8494	15.680
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	KAN2	2.4526	0.8512	15.733
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	KAN22	2.4631	0.8481	15.527
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	KAN23	2.4573	0.8533	15.764
Balochistan - Las Bela - Kanrach Valley (Kharrari)	LARCH	KAN24x2	2.4436	0.8544	15.662
Balochistan - Las Bela - Kanrach Valley(Kharrari)	LARCH	KAN25	2.4501	0.8463	15.637
Balochistan - Las Bela - Kanrach Valley (Bamph)	LARCH	KAN3	2.4542	0.8479	15.632
Balochistan - Las Bela - Kanrach Valley (Bamph)	LARCH	KAN33	2.4593	0.8433	15.613
Balochistan - Las Bela - Kanrach Valley (Bamph)	LARCH	KAN34	2.4585	0.8444	15.690
Balochistan - Las Bela - Kanrach Valley (Bamph)	LARCH	KAN35	2.4718	0.8524	15.673
Balochistan - Las Bela - Kanrach Valley (Duddar)	Siddiqui 1994: Table 7.4	SGL-104	2.4702	0.8467	15.722
Bihar - Amjhor	Balasubrahmanyan & Chandy 1976	11	2.4029	0.8915	15.610
Bihar - Amjhor	Balasubrahmanyan & Chandy 1976	12	2.3959	0.8960	15.760
Bihar - Amjhor	Balasubrahmanyan & Chandy 1976	13	2.3931	0.8977	15.620
Bihar - Hesatu-Pindara	Singh et al 2001: Table 1	TQ97-22	2.3190	0.9564	15.494
Bihar - Hesatu-Pindara	Singh et al 2001: Table 1	TQ97-23	2.3203	0.9573	15.564
Bihar - Hesatu-Pindara	Singh et al 2001: Table 1	TQ97-24	2.3201	0.9571	15.537
Bihar - Hesatu-Pindara	Singh et al 2001: Table 1	TQ97-25	2.3184	0.9563	15.498

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	*reference*	*sample*	208/207	207/206	207/204
Bihar - Hesatu-Pindara	Singh et al 2001: Table 1	TQ97-26	2.3238	0.9574	15.567
Gujarat - Banejnes (Gir Forest)	LARCH	GIR-1	2.6496	0.7789	15.657
Gujarat - Banejnes (Gir Forest)	LARCH	GIR-2	2.6628	0.7790	15.704
Gujarat - Banejnes (Gir Forest)	LARCH	GIR-3	2.6547	0.7795	15.711
Gujarat - Banejnes (Gir Forest)	LARCH	GIR-4	2.6485	0.7803	15.717
Gujarat - Banejnes (Gir Forest)	LARCH	GIR-5	2.6638	0.7789	15.727
Gujarat - Khandia	LARCH	GK1	2.3240	0.9508	15.691
Gujarat - Khandia	LARCH	GK2	2.3237	0.9506	15.702
Gujarat - Khandia	LARCH	GK3	2.3270	0.9500	15.692
Gujarat - Khandia	LARCH	GK4	2.3241	0.9518	15.699
Gujarat - Khandia	LARCH	GK5	2.3260	0.9508	15.706
Gujarat - Khandia	LARCH	GK6	2.3249	0.9515	15.710
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	Deb et al. 1989: Table III	BH115/11A	2.3876	0.9019	15.616
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	Deb et al. 1989: Table III	BH115/7	2.3883	0.9026	15.613
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	Deb et al. 1989: Table III	BH16/2	2.3869	0.9039	15.615
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	Deb et al. 1989: Table III	BH89/9	2.3875	0.9041	15.615
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	Deb et al. 1989: Table III	TQ85-29	2.3873	0.9034	15.616
Gujarat/Rajasthan - Ambaji-Sendra - Ambaji	LARCH	Ambaji Pb	2.3761	0.9127	15.833
Gujarat/Rajasthan - Ambaji-Sendra - Amli Mal	Deb et al. 2001:Table 4	TQ90-11	2.3928	0.9070	15.612
Gujarat/Rajasthan - Ambaji-Sendra - Amli Mal	Deb et al. 2001:Table 4	TQ90-12	2.3929	0.9070	15.608

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Gujarat/Rajasthan - Ambaji-Sendra - Basantgarh	Deb et al. 2001:Table 4	TQ91-43	2.3719	0.9151	15.476
Gujarat/Rajasthan - Ambaji-Sendra - Birantiya	Deb et al. 2001:Table 4	TQ92-74	2.3952	0.8977	15.680
Gujarat/Rajasthan - Ambaji-Sendra - Danva	Deb et al. 2001:Table 4	TQ92-75	2.3617	0.9270	15.351
Gujarat/Rajasthan - Ambaji-Sendra - Deri	Deb et al. 1989: Table III	DR14/4	2.3867	0.9039	15.626
Gujarat/Rajasthan - Ambaji-Sendra - Deri	Deb et al. 1989: Table III	DR9/14	2.3881	0.9035	15.623
Gujarat/Rajasthan - Ambaji-Sendra - Deri	Deb et al. 1989: Table III	DR9/9	2.3871	0.9039	15.622
Gujarat/Rajasthan - Ambaji-Sendra - Deri	Deb et al. 1989: Table III	Dupl.	2.3888	0.9035	15.628
Gujarat/Rajasthan - Ambaji-Sendra - Kumbariya	Deb et al. 2001:Table 4	4	2.3853	0.9019	15.656
Haryana - Tosham	Deb et al. 2001:Table 4	TQ89-8	2.4165	0.8833	15.727
Himachal Pradesh - Amba Kala	LARCH	AKHP1	2.4409	0.8498	15.732
Himachal Pradesh - Amba Kala	LARCH	AKHP2	2.4381	0.8542	15.716
Himachal Pradesh - Amba Kala	LARCH	AKHP3	2.4388	0.8496	15.754
Himachal Pradesh - Amba Kala	LARCH	AKHP4	2.4385	0.8518	15.728
Himachal Pradesh - Amba Kala	LARCH	AKHP5	2.4407	0.8495	15.748
Himachal Pradesh - Panuh	LARCH	HPP-1	2.4526	0.8416	15.872
Himachal Pradesh - Panuh	LARCH	HPP-1B	2.4513	0.8416	15.866
Himachal Pradesh - Panuh	LARCH	HPP-2	2.4522	0.8435	15.939
Himachal Pradesh - Panuh	LARCH	HPP-2C	2.4509	0.8427	16.021
Himachal Pradesh - Panuh	LARCH	HPP-3	2.4588	0.8431	15.950
Himachal Pradesh - Panuh	LARCH	HPP-3B	2.4529	0.8408	15.885

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	*reference*	*sample*	208/207	207/206	207/204
Himachal Pradesh - Panuh	LARCH	HPP-4	2.4535	0.8446	15.934
Himachal Pradesh - Panuh	LARCH	HPP-4B	2.4559	0.8419	15.911
Himachal Pradesh - Panuh	LARCH	HPP-5	2.4531	0.8448	15.944
Himachal Pradesh - Panuh	LARCH	HPP-5B	2.4606	0.8419	15.911
Himachal Pradesh - Tal	LARCH	HPT-1	2.4538	0.8329	16.133
Himachal Pradesh - Tal	LARCH	HPT-2	2.4597	0.8308	16.072
Himachal Pradesh - Tal	LARCH	HPT-3	2.4608	0.8306	16.020
Himachal Pradesh - Tal	LARCH	HPT-4	2.4525	0.8318	16.087
Himachal Pradesh - Tal	LARCH	HPT-5	2.4538	0.8314	16.059
Himachal Pradesh - Uchich	LARCH	HPU-1	2.5775	0.7102	15.832
Himachal Pradesh - Uchich	LARCH	HPU-2	2.5720	0.7119	15.499
Himachal Pradesh - Uchich	LARCH	HPU-3	2.5665	0.7081	15.501
Himachal Pradesh - Uchich	LARCH	HPU-5	2.5758	0.7135	16.145
Himachal Pradesh - Uchich	LARCH	HPU-4	2.5828	0.7059	15.299
Jammu & Kashmir - Buniyar	LARCH	RB2	2.3525	0.9066	15.473
Jammu & Kashmir - Buniyar	LARCH	rb2-2	2.3346	0.9115	15.381
Jammu & Kashmir - Buniyar	LARCH	RB3	2.3605	0.9093	15.538
Jammu & Kashmir - Buniyar	LARCH	RB3-2	2.3601	0.9060	15.557
Jammu & Kashmir - Buniyar	LARCH	RB3B	2.3513	0.9080	15.592
Jammu & Kashmir - Buniyar	LARCH	RB4	2.3434	0.9084	15.425

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman					
region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Jammu & Kashmir - Buniyar	LARCH	RB4-2	2.3554	0.9101	15.575
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK1	2.3589	0.9108	15.600
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK2	2.3572	0.9127	15.602
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK3	2.3580	0.9112	15.599
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK4	2.3586	0.9109	15.576
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK5	2.3583	0.9110	15.603
Jammu & Kashmir - Riasi (Kheri Kot)	LARCH	KK6	2.3571	0.9115	15.599
Jammu & Kashmir - Riasi (Darabi)	LARCH	RD1	2.3472	0.9282	15.660
Jammu & Kashmir - Riasi (Darabi)	LARCH	RD1A	2.3390	0.9278	15.983
Jammu & Kashmir - Riasi (Darabi)	LARCH	RD2	2.3528	0.9164	16.780
Jammu & Kashmir - Riasi (Darabi)	LARCH	RD3	2.3591	0.9169	15.824
Jammu & Kashmir - Riasi (Darabi)	LARCH	RD4	2.3578	0.9172	16.168
Jammu & Kashmir - Riasi (Sersendu)	Raha et al 1978: Table II	0.25	2.3686	0.9171	15.600
Jammu & Kashmir - Riasi (Sersendu)	Raha et al 1978: Table II	I/3	2.3697	0.9138	15.470
Jammu & Kashmir - Riasi (Sersendu)	Raha et al 1978: Table II	II/2	2.3631	0.9105	15.560
Jammu & Kashmir - Riasi (Sersendu)	Raha et al 1978: Table II	II/I	2.3688	0.9178	15.510
NWFP - Besham (Lahor)	Shah et al. 1992: Table 1	n/a	2.2878	1.0193	15.085
NWFP - Besham (Lahor)	Shah et al. 1992: Table 1	n/a	2.2883	1.0172	15.097
NWFP - Besham (Lahor)	Shah et al. 1992: Table 1	n/a	2.2892	1.0192	15.106
NWFP - Besham (Pazang)	Shah et al. 1992: Table 1	n/a	2.2864	1.0131	15.116

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman					
region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
NWFP - Besham (Pazang)	Shah et al. 1992: Table 1	n/a	2.2865	1.0170	15.096
NWFP - Chitral	Tahirkheli et al. 1997: Table 1	Tz203	2.4930	0.8361	15.660
NWFP - Chitral	Tahirkheli et al. 1997: Table 1	Tz5	2.4971	0.8371	15.730
NWFP - Chitral	Tahirkheli et al. 1997: Table 1	Tz8	2.4962	0.8349	15.680
Oman - Qumayrah	Calvez and Lescuyer 1991: Table 1	JL90-35	2.4810	0.8376	15.689
Oman - Semail Ophiolite	Chen and Pallister 1981: Table 1	OMG-15	2.4766	0.8408	15.719
Oman - Wadi Mayh	Calvez and Lescuyer 1991: Table 1	C533	2.4535	0.8624	15.734
Rajasthan - Khera Mawal	Deb et al. 2001:Table 4	TQ95-45	2.4641	0.8609	15.778
Rajasthan - Khera Mawal	LARCH	RKM1	2.4449	0.8616	15.526
Rajasthan - Khera Mawal	LARCH	RKM2	2.4400	0.8615	15.515
Rajasthan - Khera Mawal	LARCH	RKM3	2.4433	0.8618	15.530
Rajasthan - Khera Mawal	LARCH	RKM4	2.4425	0.8603	15.459
Rajasthan - Lohakhan	LARCH	point119	2.3106	0.9544	15.650
Rajasthan - Punagarh Hill	Deb et al. 2001:Table 4	TQ96-3	2.4031	0.8851	15.787
Rajasthan - Punagarh Hill	Deb et al. 2001:Table 4	TQ96-4	2.3942	0.8863	15.780
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	5	2.3050	0.9610	15.510
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	6	2.2688	0.9635	15.590
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	7	2.3059	0.9682	15.530
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	8	2.3155	0.9706	15.530
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	9	2.2995	0.9621	15.490

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman

region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Rajasthan - Rajpura-Dariba	Balasubrahmanyan & Chandy 1976	10	2.2987	0.9592	15.500
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	Dupl.	2.3102	0.9660	15.486
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	Dupl.	2.3110	0.9660	15.492
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	Dupl.	2.3112	0.9657	15.494
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/208	2.3116	0.9660	15.490
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/224	2.3114	0.9658	15.488
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/231	2.3097	0.9658	15.488
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/247	2.3109	0.9660	15.485
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/263	2.3109	0.9660	15.494
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/27	2.3115	0.9655	15.488
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/28	2.3099	0.9659	15.499
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/305	2.3109	0.9658	15.490
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/52	2.3109	0.9658	15.489
Rajasthan - Rajpura-Dariba	Deb et al. 1989: Table III	RD400/8	2.3110	0.9662	15.492
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3106	0.9657	15.503
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3110	0.9655	15.506
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3111	0.9657	15.505
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3112	0.9659	15.507
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3114	0.9659	15.506
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	Dupl.	2.3124	0.9658	15.498

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman					
region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RA/OD/5	2.3111	0.9657	15.499
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RA/OD/7	2.3104	0.9658	15.495
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RA84/A	2.3117	0.9657	15.507
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RA84/B	2.3109	0.9656	15.509
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RA84/C	2.3117	0.9658	15.504
Rajasthan - Rampura-Agucha	Deb et al. 1989: Table III	RD400/8	2.3120	0.9658	15.512
Rajasthan - Saladipura	Deb et al. 1989: Table III	Dupl.	2.3118	0.9642	15.492
Rajasthan - Saladipura	Deb et al. 1989: Table III	TQ 85-24	2.3126	0.9642	15.498
Rajasthan - Sawai Madhopur	LARCH	RSM-1	2.3187	0.9464	15.805
Rajasthan - Sawai Madhopur	LARCH	RSM-2	2.3114	0.9494	15.788
Rajasthan - Sawai Madhopur	LARCH	RSM-3	2.3140	0.9502	15.802
Rajasthan - Sawai Madhopur	LARCH	RSM-4	2.3227	0.9494	15.731
Rajasthan - Sawai Madhopur	LARCH	RSM-5	2.3128	0.9524	15.831
Rajasthan - Zawar	Balasubrahmanyan & Chandy 1976	1	2.3195	0.9520	15.680
Rajasthan - Zawar	Balasubrahmanyan & Chandy 1976	2	2.3152	0.9462	15.640
Rajasthan - Zawar	Balasubrahmanyan & Chandy 1976	3	2.3227	0.9456	15.650
Rajasthan - Zawar	Balasubrahmanyan & Chandy 1976	4	2.3179	0.9512	15.600
Rajasthan - Zawar Mines	LARCH	Zawar Pb	2.3227	0.9479	15.674

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman					
region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Rajasthan - Zawar-Baroi	Deb et al. 1989: Table III	BM4	2.3234	0.9483	15.706
Rajasthan - Zawar-Baroi	Deb et al. 1989: Table III	BM6	2.3253	0.9479	15.723
Rajasthan - Zawar-Baroi	Deb et al. 1989: Table III	BM7	2.3217	0.9488	15.683
Rajasthan - Zawar-Baroi	Deb et al. 1989: Table III	Dupl.	2.3232	0.9478	15.721
Rajasthan - Zawarmala	Deb et al. 1989: Table III	Dupl.	2.3237	0.9477	15.725
Rajasthan - Zawarmala	Deb et al. 1989: Table III	Dupl.	2.3241	0.9467	15.698
Rajasthan - Zawarmala	Deb et al. 1989: Table III	Dupl.	2.3248	0.9471	15.708
Rajasthan - Zawarmala	Deb et al. 1989: Table III	ZM14	2.3249	0.9469	15.708
Rajasthan - Zawarmala	Deb et al. 1989: Table III	ZM22	2.3225	0.9476	15.694
Rajasthan - Zawarmala	Deb et al. 1989: Table III	ZM27	2.3245	0.9489	15.694
Rajasthan - Zawarmala	Deb et al. 1989: Table III	ZM5	2.3233	0.9479	15.722
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	BL5	2.3215	0.9499	15.666
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	BL9	2.3215	0.9500	15.660
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	Dupl.	2.3209	0.9499	15.657
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	Dupl.	2.3221	0.9503	15.670
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	ZMC15	2.3219	0.9502	15.663
Rajasthan - Zawar-Mochia	Deb et al. 1989: Table III	ZMC2	2.3222	0.9502	15.672

Appendix 12.1 (cont.): Pb isotope data for ore samples from lead deposits in India, Pakistan and Oman					
region - deposit	***reference***	***sample***	**208/207**	**207/206**	**207/204**
Sikkim - Rangpo	Sarkar et al. 2000: Table 1	MAHW/17/B/7	2.3030	0.9740	15.410
Sikkim - Rangpo	Sarkar et al. 2000: Table 1	MAHW/17/R/6	2.2805	0.9736	15.457
Sikkim - Rangpo	Sarkar et al. 2000: Table 1	NAB-3/P/5	2.3009	0.9735	15.386
Sikkim - Rangpo	Sarkar et al. 2000: Table 1	NAFW/2/R/8	2.3012	0.9736	15.400
Uttaranchal - Askot	LARCH	AS28B	2.2970	0.9700	15.457
Uttaranchal - Askot	LARCH	RR-84-B2	2.2880	0.9718	15.329
Uttaranchal - Askot	LARCH	RR85	2.3001	0.9727	15.966
Uttaranchal - Bageshwar	Sarkar et al. 2000: Table 1	B6-1	2.3121	0.9576	15.551
Uttaranchal - Bageshwar	Sarkar et al. 2000: Table 1	B6-2	2.3176	0.9471	15.555
Uttaranchal - Bageshwar	Sarkar et al. 2000: Table 1	B6-3	2.3127	0.9572	15.541
Uttaranchal - Khansue	LARCH	GK74/1	2.3720	0.8513	15.729
Uttaranchal - Khansue	LARCH	GK74/3	2.3803	0.8540	15.743
West Bengal - Gorubathan	Sarkar et al. 2000: Table 1	D2/6/4	2.2955	0.9726	15.511
West Bengal - Gorubathan	Sarkar et al. 2000: Table 1	K5/6/1	2.3011	0.9729	15.428
West Bengal - Gorubathan	Sarkar et al. 2000: Table 1	S/31/6/3	2.3028	0.9741	15.420

Appendix 12.2: Pb isotope data for 19 archaeological lead ore fragments from Harappa							
artifact number	**material**	**mound-trench**	**context**	**208/207**	**207/206**	**207/204**	**probable geologic provenience**
H93/4001-1	galena	ET - 10	surface	2.3666	0.9100	15.616	Jammu and Kashmir
H96/7512-10	galena	AB - 39	Period 1	2.3432	0.9100	15.578	Jammu and Kashmir
H89/1038-21	galena	AB / E - 53	disturbed	2.3577	0.9086	15.641	Jammu and Kashmir
H90/3011-147	galena	E - survey	surface	2.4411	0.8584	15.759	unclear at this time
H90/3011-148	galena	E - survey	surface	2.4366	0.8613	15.763	unclear at this time
H99/7649-31	galena	F- 41	Period 3C	2.3556	0.9107	15.599	Jammu and Kashmir
H98/8158-62	galena	E - 11	Period 3C	2.3543	0.9116	15.576	Jammu and Kashmir
H2000/2102-143	galena	E - 54	disturbed	2.3548	0.9141	15.603	Jammu and Kashmir
H2000/2101-1726	galena	E - 54	disturbed	2.3577	0.9055	15.628	Jammu and Kashmir
H2000/2226-111	galena	E - 54	disturbed	2.3545	0.9099	15.626	Jammu and Kashmir
H2000/9999-73	galena	E - survey	surface	2.3562	0.9115	15.579	Jammu and Kashmir
H99/8857-1	cerussite-anglesite	E - 11	disturbed	2.4721	0.8469	15.701	southern Balochistan
H99/8755-152	cerussite-anglesite	F - 43	Period 3C	2.4608	0.8474	15.738	southern Balochistan
H2000/2139-141	cerussite-anglesite	E - 54	disturbed	2.4731	0.8455	15.635	southern Balochistan
H2000/2342-40	massicot	E - 54	disturbed	2.4351	0.8586	15.815	southern Balochistan
H88/715-15	massicot	E - 52	Period 3C	2.4677	0.8466	15.704	southern Balochistan
H90/3030-1	massicot	E - 1	disturbed	2.4197	0.8673	15.758	unclear at this time
H2001/9091-1	massicot	E - 11	Period 3C	2.4443	0.8651	15.639	unclear at this time
H90/3193-6	massicot	E - 58	Period 3C	2.4629	0.8443	15.636	southern Balochistan

Appendix 12.3: Pb isotope data for lead artifacts, slags, lumps and residues from Harappa

artifact number	material	mound-trench	context	208/207	207/206	207/204	probable geologic provenience
H93/3506-43	lead rod	E - 1	disturbed	2.4368	0.8689	15.797	Unclear at this time
H88/197-1	wulfenite rod	cemetery	Period 3B	2.3479	0.9093	15.585	Jammu and Kashmir
H2000/2174-321	inscribed lead bar	E - 54	surface	2.4631	0.8486	15.634	southern Balochistan
H94/4891-214	lead piece	ET - 27	Period 3C	2.4497	0.8653	15.720	unclear at this time (Oman?)
H2000/2102-1555	lead bar	E - 54	disturbed	2.4490	0.8644	15.606	unclear at this time (Oman?)
H2000/2226-50	lead bar/chisel	E - 54	disturbed	2.4505	0.8460	15.667	southern Balochistan
H88/446-04	lead repair plug in shell ladle	cemetery	Period 3B	2.4379	0.8662	15.690	Unclear at this time
H93/3892-69	porous slag with lead inclusions	E - 8	surface	2.4654	0.8433	15.701	southern Balochistan
H93/3563-13	slag with yellow encrustation	E - 4	Period 3C	2.4555	0.8634	15.679	Unclear at this time
H95/6006-1	melted lead lump	north of F	surface	2.4689	0.8436	15.731	southern Balochistan
H2001/11701-6	melted lead lump	E - 11	surface	2.3575	0.9140	15.548	Jammu and Kashmir
H93/3511-37	slag w/ green and yellow encrustation	E - 1	disturbed	2.4136	0.8738	15.514	Unclear at this time
H93/3804-5	slag w/ green and yellow encrustation	E - 5	disturbed	2.4573	0.8556	15.597	southern Balochistan
H87/539-80	lead residue inside “surma” bottle	AB - 50	Period 3C	2.3558	0.9074	15.806	Jammu and Kashmir
H98/8158-26	lead residue inside “surma” bottle	E - 11	Period 3C	2.3690	0.9115	15.753	Jammu and Kashmir
[HM 9697 V3906]	lead residue inside “surma” bottle	Unknown	Unknown	2.3472	0.9114	15.799	Jammu and Kashmir

Appendix 12.4: Pb isotope data for lead artifacts from Shahr-i-Sokhta, Mundigak, Mehrgarh, Nausharo and Mohenjo-daro.

site	analysis # / artifact number	artifact type	208/207	207/206	207/204
Shahr-i-Sokhta	SiS151	galena fragment	2.4704	0.8497	15.606
Shahr-i-Sokhta	SiS11390	galena fragment	2.4747	0.8412	15.599
Mundigak	MGK-1 / MGB 36 CLXXXVII (3)	galena fragment	2.4727	0.8510	15.714
Mundigak	MGK-2 / MG G91 (3)	galena fragment	2.4678	0.8517	15.704
Mundigak	MGK-3 / no #	galena fragment	2.4792	0.8488	15.665
Mundigak	MGK-4 / MGA XXXII *a*	galena fragment	2.4629	0.8488	15.630
Mundigak	MGK-5 / MGA XXXII *b*	galena fragment	2.4609	0.8488	15.661
Mundigak	MGK-6 / MGA XXXII *c*	galena fragment	2.4653	0.8480	15.596
Mundigak	MGK-7 / no #	galena fragment	2.4793	0.8504	15.664
Mundigak	MGK-8 / no #	galena fragment	2.4691	0.8501	15.659
Mundigak	MGK-9 / no #	galena fragment	2.4763	0.8497	15.663
Mundigak	MGK-10 / MG J12 Tepe A	lead sheet	2.4658	0.8412	15.562
Mundigak	MGK-11 / MG J12 Tepe A	lead sheet	2.4744	0.8390	15.611
Mundigak	MGK-12 / MG 6.1	lead ring	2.4774	0.8459	15.643
Mundigak	MGK-14 / no #	galena fragment	2.4811	0.8503	15.681
Mehrgarh	MR-L1 / MR4 F6B (2) – large (MR 78 04 11 24)	galena fragment	2.4641	0.8467	15.755
Mehrgarh	MR-L2 / MR4 F6B (2) – small (MR 78 04 11 25)	galena fragment	2.4710	0.8482	15.767
Mehrgarh	MR-L3 / MR4 F6B (2) *c* (MR 78 04 11 26)	galena fragment	2.4585	0.8485	15.749
Mehrgarh	MR-L4 / MR79.04.73.59	galena fragment	2.4657	0.8469	15.708
Mehrgarh	MR-L5 / L31121	galena fragment	2.4698	0.8458	15.702
Mehrgarh	MR-L6 / L31122	galena fragment	2.4800	0.8446	15.708
Mehrgarh	MR-L7 / MR4 F6B (1) 78 (MR 78 04 10 31)	galena fragment	2.4759	0.8442	15.681
Nausharo	NS-L1 / NS-9111 6303 loc. XII	lead ring	2.4719	0.8447	15.697
Mohenjo-daro	MD-S / no #	"surma" bottle residue	2.4316	0.8660	15.516
Mohenjo-daro	MD-L1 / MD-88 711	galena fragment	2.4668	0.8437	15.672

Appendix 12.5: Pb isotope data for silver artifacts from Allahdino, Mohenjo-daro, Mundigak and Nagwada

Site	analysis number	accession number	artifact type	208/207	207/206	207/204
Mundigak	MGK-13	MGB 40 CXCIX	ring	2.4938	0.8353	15.629
Nagwada	NGW-1	n/a	ring fragment	2.4677	0.8522	15.685
Mohenjo-daro	NM-1	50.47, S. no 12	bangle	2.4462	0.8636	15.624
Mohenjo-daro	NM-1	NMP#8	bead	2.4468	0.8652	15.577
Mohenjo-daro	NM-1	NMP#8	bead	2.4437	0.8629	15.538
Mohenjo-daro	NM-1	NMP#8	bead	2.4420	0.8672	15.548
Mohenjo-daro	NM-1	NMP#50.22/6	button or nose stud	2.4304	0.8701	15.473
Allahdino	AD-1	2070 A	large flat bead with triple hole	2.4695	0.8455	15.666
Allahdino	AD-2	2070 B	large flat bead with triple hole	2.4651	0.8494	15.583
Allahdino	AD-3	2101 A	small bead	2.4647	0.8520	15.343
Allahdino	AD-4	2101 B	small bead	2.4608	0.8500	15.474
Allahdino	AD-5	2101 C	bead	2.4429	0.8539	15.487
Allahdino	AD-6	2101 E	bead	2.4478	0.8569	15.623
Allahdino	AD-7	2101 F	bead	2.4607	0.8511	15.604
Allahdino	AD-8	2111 A	toe ring	2.4709	0.8466	15.674
Allahdino	AD-9	2111 B	bead	2.4409	0.8705	15.747
Allahdino	AD-10	2111 B	lump of twisted bands	2.4561	0.8481	15.655

Appendix 12.6: Pb isotope data for the argentiferous galena deposit at Nakhlak, Iran (extrapolated from Stos-Gale 2001: Table 4.1)

Sample number	Material	208/207	207/206	207/204
Pb-835	Litharge	2.4738	0.84509	15.690
Pb-833	Pb slag/litharge	2.4715	0.84479	15.647
Pb-832	Cerussite	2.4743	0.84480	15.645
Pb-834	galena	2.4710	0.84525	15.670
PI 1b	Pb slag	2.4712	0.84468	15.654
PI 2	Pb slag	2.4706	0.84466	15.651
PI 1a	Pb slag	2.4710	0.84463	15.655

Appendix 12.7: Pb isotope data for copper ores and slags from deposits in India, Pakistan, Iran and Oman

Region	source	material	reference	analysis #	208/207	207/206	207/204
Balochistan	Chagai-Saindak	ore	LARCH	ChCu1	2.4878	0.8327	15.782
Balochistan	Chagai-Saindak	ore	LARCH	ChCu2	2.4802	0.8407	15.828
Balochistan	Chagai-Saindak	ore	LARCH	ChCu3	2.4763	0.8421	15.729
Balochistan	Chagai-Saindak	ore	LARCH	ChCu4	2.4697	0.8424	15.758
Balochistan	Chagai-Saindak	ore	LARCH	ChCu5	2.4728	0.8447	15.797
Balochistan	Chagai-Saindak	ore	LARCH	ChCu6	2.4838	0.8434	15.704
Balochistan	Chagai-Saindak	ore	LARCH	ChCu7	2.4911	0.8315	15.807
Gujarat	Ambaji	ore	LARCH	GN-01	2.3950	0.9111	15.890
Gujarat	Ambaji	ore	LARCH	GN-02	2.4027	0.9106	15.396
Gujarat	Ambaji	ore	LARCH	GN-03	2.4035	0.9079	15.862
Gujarat	Ambaji	ore	LARCH	GN-04	2.3916	0.8995	15.771
Gujarat	Ambaji	ore	LARCH	GN-05	2.4041	0.8795	15.706
Gujarat	Ambaji	ore	LARCH	GN-06	2.3977	0.8976	15.685
Gujarat	Ambaji	ore	LARCH	GN-07	2.3889	0.8991	15.693
Gujarat	Ambaji	ore	LARCH	GN-08	2.3861	0.8972	15.647
Gujarat	Ambaji	ore	LARCH	GN-09	2.3858	0.8970	15.647
Gujarat	Ambaji	ore	LARCH	GN-10	2.3879	0.8991	15.677
Gujarat	Ambaji	ore	Hegde and Ericson 1985	no #	2.3891	0.9040	15.649

Appendix 12.7(cont.): Pb isotope data for copper ores and slags from deposits in India, Pakistan, Iran and Oman (*archaeological)							
Region	**source**	**material**	**reference**	**analysis #**	**208/207**	**207/206**	**207/204**
Himachal Pradesh	Chargaon	ore	LARCH	HP1	2.6692	0.6834	16.639
Himachal Pradesh	Chargaon	ore	LARCH	HP2	2.6706	0.6801	16.662
Himachal Pradesh	Chargaon	ore	LARCH	HP3	2.6701	0.6813	16.690
Himachal Pradesh	Chargaon	ore	LARCH	HP4	2.6756	0.6801	16.678
Himachal Pradesh	Chargaon	ore	LARCH	HP5	2.6650	0.6812	16.702
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 96	2.4891	0.8348	15.639
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 101/1	2.4935	0.8341	15.643
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 137	2.4934	0.8336	15.631
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 145	2.4861	0.8120	15.661
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 148	2.4933	0.8319	15.617
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 156A	2.4898	0.8193	15.656
Iran	Shahr-i-Sokhta	ore*	Hauptmann et al. 2003	SS 161	2.4950	0.8329	15.624
Iran	Chechel Kureh	ore	Hauptmann et al. 2003	E 127/4111	2.4899	0.8394	15.657
Iran	Chechel Kureh	ore	Hauptmann et al. 2003	E 128/4112	2.4879	0.8389	15.659
Iran	Qaleh Zari	ore	Hauptmann et al. 2003	E 128/4286	2.4913	0.8349	15.662
Iran	Qaleh Zari	ore	Hauptmann et al. 2003	E 130/4661	2.4906	0.8347	15.665

Appendix 12.7(cont.): Pb isotope data for copper ores and slags from deposits in India, Pakistan, Iran and Oman							
Region	**source**	**material**	**reference**	**analysis #**	**208/207**	**207/206**	**207/204**
Oman	Aarja	ore	Chen and Pallister 1981	Aarja	2.4484	0.8601	15.459
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS12	2.4104	0.8797	15.668
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS18	2.4435	0.8699	15.501
Oman	Al Ajal	ore	Calvez and Lescuyer 1991	PS17	2.4446	0.8615	15.515
Oman	Bayda	ore	Chen and Pallister 1981	Bayada	2.4433	0.8627	15.438
Oman	Daris 1	ore	Calvez and Lescuyer 1991	PS5	2.4507	0.8559	15.488
Oman	Daris 1	ore	Calvez and Lescuyer 1991	PS4	2.4532	0.8557	15.443
Oman	Daris 2	ore	Calvez and Lescuyer 1991	PS2	2.4676	0.8454	15.600
Oman	Daris 2	ore	Calvez and Lescuyer 1991	PS1	2.4670	0.8459	15.547
Oman	Gaddamah (near Lasail)	ore	Calvez and Lescuyer 1991	CU54	2.4593	0.8545	15.533
Oman	Hayl as Safil	ore	Calvez and Lescuyer 1991	CJ55	2.4647	0.8453	15.603
Oman	Hayl as Safil	ore	Calvez and Lescuyer 1991	PS16	2.4550	0.8535	15.461
Oman	Lasail	ore	Chen and Pallister 1981	Lasail	2.4412	0.8564	15.427
Oman	Maqa'il	ore	Calvez and Lescuyer 1991	CU73	2.4613	0.8530	15.544
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS9	2.4650	0.8466	15.620
Oman	Rakah	ore	Calvez and Lescuyer 1991	CJ58	2.4678	0.8444	15.602
Oman	Rakah	ore	Calvez and Lescuyer 1991	CJ57	2.4680	0.8438	15.606
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS6	2.4682	0.8431	15.608
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS8	2.4683	0.8437	15.608
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS7	2.4691	0.8438	15.593
Oman	Rakah	ore	Calvez and Lescuyer 1991	PS10	2.4701	0.8454	15.607
Oman	Zuha	ore	Calvez and Lescuyer 1991	CU24	2.4439	0.8568	15.451

Appendix 12.7(cont.): Pb isotope data for copper ores and slags from deposits in India, Pakistan, Iran and Oman							
Region	**source**	**material**	**reference**	**analysis #**	**208/207**	**207/206**	**207/204**
Rajasthan	Ganeshwar	slag	LARCH	RNSG_13	2.4613	0.8513	15.754
Rajasthan	Ganeshwar	slag	LARCH	RNSG2.2	2.4481	0.8560	15.701
Rajasthan	Ganeshwar	slag	LARCH	RNSG2.2_14	2.4345	0.8682	15.849
Rajasthan	Ganeshwar	slag	LARCH	RNSG2.5	2.4249	0.8674	15.567
Rajasthan	Ganeshwar	slag	LARCH	RNSG2_10	2.4534	0.8552	15.717
Rajasthan	Ganeshwar	slag	LARCH	RNSG2_11	2.4304	0.8689	15.745
Rajasthan	Ganeshwar	slag	LARCH	RNSG2_12	2.4392	0.8662	15.723
Rajasthan	Ganeshwar	slag	LARCH	RNSG7	2.4281	0.8728	15.538
Rajasthan	Ganeshwar	slag	LARCH	RNSG6	2.4304	0.8688	15.679
Rajasthan	Ganeshwar	slag	LARCH	RNSG8	2.4218	0.8654	15.824
Rajasthan	Ganeshwar	slag	LARCH	RNSG9	2.4246	0.8634	15.565
Rajasthan	Singhana	slag	LARCH	RNSS4	2.3798	0.8856	15.853
Rajasthan	Singhana	slag	LARCH	RNSS5	2.3845	0.8863	15.608
Rajasthan	Singhana	slag	LARCH	RNSS7	2.4338	0.8603	15.723
Rajasthan	Singhana	slag	LARCH	RNSS8	2.4354	0.8637	15.616
Rajasthan	Piplawas	ore	Hegde and Ericson 1985	no #	2.2803	0.9844	15.444
Rajasthan	Kankaria	ore	Hegde and Ericson 1985	no #	2.3141	0.9630	15.524

Appendix 12.7(cont.): Pb isotope data for copper ores and slags from deposits in India, Pakistan, Iran and Oman							
Region	**source**	**material**	**reference**	**analysis #**	**208/207**	**207/206**	**207/204**
Uttaranchal	Askot	ore	LARCH	UT1	2.3351	0.9547	15.746
Uttaranchal	Askot	ore	LARCH	UT10	2.3094	0.9755	15.659
Uttaranchal	Askot	ore	LARCH	UT2	2.3013	0.9813	15.727
Uttaranchal	Askot	ore	LARCH	UT4	2.3034	0.9823	15.518
Uttaranchal	Askot	ore	LARCH	UT5	2.3017	0.9841	15.708
Uttaranchal	Askot	ore	LARCH	UT6	2.3001	0.9820	15.686
Uttaranchal	Askot	ore	LARCH	UT7	2.3023	0.9799	15.639
Waziristan	Shinkai	ore	LARCH	WAZ-1	2.4671	0.8467	15.668
Waziristan	Shinkai	ore	LARCH	WAZ-2	2.4674	0.8478	15.664
Waziristan	Shinkai	ore	LARCH	WAZ-3	2.4768	0.8462	15.644
Waziristan	Shinkai	ore	LARCH	WAZ-4	2.4812	0.8444	15.573
Waziristan	Shinkai	ore	LARCH	WAZ-5	2.4799	0.8465	15.603

Appendix 12.8: Pb isotope data for seven copper ores from Harappa					
artifact number	**ore type**	**Context**	**208/207**	**207/206**	**207/204**
H94/4999-529	chalcocite	misc. surface find period unknown	2.4454	0.8485	15.312
H90/3008-13	chalcocite	Mound E – survey, Period 3 or Later	2.4678	0.8434	15.309
H90/2070-12	chalcocite	Mound E – survey, Period 3 or Later	2.4593	0.8452	15.479
H90/3008-14	chalcocite	Mound E – survey, Period 3 or Later	2.4373	0.8610	15.148
H90/3022-98	malachite	Mound E – Tr. 58 Period 3 or later	2.4652	0.8470	15.531
H95/4943-8	malachite	Mound ET – Tr. 28 Period 3 or later	2.4642	0.8473	15.203
H90/3126-1	malachite	Mound E – Tr. 56 Period 3C	2.4639	0.8450	15.419

Appendix 13.1: Possible routes from the Indus Basin to the site of Shortughaï

There are numerous possible routes that Indus Civilization peoples may have taken when traveling to the site of Shortughaï in northern Afghanistan. The major ones emanating from the upper Indus Basin were depicted on Figure 13.9 in Chapter 13. Before reviewing the routes that I believe are suggested by rock and mineral acquisition patterns at Harappa, it is important to at least briefly acknowledge some alternate possibilities. First of all, when journeying to the Shortughaï it is not impossible that Harappans circumvented the Hindu Kush Mountains of Afghanistan altogether, traveling instead toward the west-northwest through the Helmand region and then north to southern Central Asia (Turkmenia). From there they could have continued due east to Bactria and, eventually, Shortughaï. Although this is a circuitous way to get to northern Afghanistan, Francfort points out that (1984a: 172) the Helmand route "is the most probable one between the Harappan world and Turkmenia," where Indus materials have been found at sites like Altyn Depe (Masson 1981). For this reason it should not be ruled out. It is also possible that Harappans utilized a northerly route to Shortughaï but bypassed the highland regions directly west and north of the upper Indus Basin. They could have began such a journey in the lower Indus Basin, traveled via the Bolan and Khojak passes of Balochistan into southeastern Afghanistan and from there moved northward to their destination through the Tarnak Valley and over the Sher-i-Dana and Saling passes. The shortest and most direct routes to Shortughaï from Harappan territory, however, would have originated in the upper Indus Basin. Below I discuss several possibilities.

Harappans from the upper Indus Basin might have embarked on their journey to Shortughaï by first traveling due west, through the Sanghar Pass in the central Sulaiman Range and into northern Balochistan. Travel in this direction would likely have taken them past the large Indus Civilization site of Dabar Kot in the Loralai Valley and, eventually, into the southern Zhob Valley. From there they could have continued west to the Khojak Pass and picked up the second alternate route described in the preceding paragraph or turned north toward the Gomal route, which will be discussed next. Much of the grindingstone, alabaster and some of the vesuvianite-grossular utilized at Harappa (and maybe even white Parh limestone from Loralai too) could have been acquired directly along this northern Balochistan route.

The Gomal Plain may have been an important embarkation area for Harappans traveling to northern Afghanistan. A number of Indus Civilization settlements are now known to have existed in that region including Ghandi Umar Khan, which is located near the Gomal River itself. Harappans could have followed that river to its headwaters, crossed into eastern Afghanistan via the Gomal Pass and then traveled north to their destination from there. Along the way they would have passed not far from the highland Harappan site of Periano Ghundai. Some of the grindingstone and alabaster acquired by residents of Harappa came from sources near the beginning of this route, which Markham noted (1879: 53) was one of the more historically important links between Central Asia and India.

Two main routes lead from the Bannu Basin into eastern Afghanistan – one follows the Tochi River and the other the Kurram River (Thomas and Knox 1994: 93). From their termini near the modern cities of Ghazni and Kabul (respectively) the traveler could

continue on to regions in the north. Although the Kurram route, in particular, was a major thoroughfare for traders and invaders alike during the historic period (Markham 1879: 47-50), it is unclear if it might have also been for Indus Civilization peoples. Some of the raw steatite acquired by residents of Harappa and Mohenjo-Daro may well have come from a source in the Safed Koh Range, which forms part of the northern boundary of the Kurram River Valley. However, no trace of a Harappan presence within the Bannu Basin has been detected in over two decades of archaeological exploration there (Khan et al. 2002: 89).

No Indus Civilization sites (save for Shortughaï) have been discovered north of the Salt Range either. However, there is good reason to suppose that an important route for Harappans journeying to and from northern Afghanistan may have traversed those mountains and proceeded across the Potwar Plateau and through the Peshawar Valley. It has been shown that, during Period 3 at Harappa, site residents acquired alabaster (along with Mari "Diamonds") from the Salt Range, large amounts of steatite from sources not far to the north of the Potwar Plateau, and steatite, vesuvianite-grossular and, perhaps, some chert from occurrences on the margins of the Peshawar Valley. It is highly likely (but not yet confirmed) that they acquired gold, amazonite, mica, nephrite, serpentine and many other varieties of stone and metal from those regions as well. Although Harappans might have obtained these raw materials through one of the other interaction scenarios discussed on pp. 757-760, it is probable that, at least at times, they traveled to or near the actual sources themselves. I have argued (pp. 373-374, 420) that in order to identify deposits of white-firing steatite it would have been necessary conduct high-temperature experimental firings and that this would have required technological expertise that Northern Neolithic

peoples may not have possessed. If Harappans were the ones who conducted such firings then it is likely that, rather than transport samples hundreds of kilometers to the south, they would have tested them at or near potential sources in the north.

From the Peshawar Valley, Harappans had several options for their onward journey to Shortughaï. They could have traveled west into Afghanistan via the Khyber Pass (passing just 10 km north of the Landi Kotal steatite deposit) and then, upon reaching the Kabul Valley, headed north over the Saling Pass into northern Afghanistan. Or they might have turned eastward before Saling and traveled up the Panjshir Valley and over the Anjuman Pass to the lapis lazuli mines of Badakhshan. From there they would have needed only to have followed the Kokcha River 200 km downstream to its confluence with the Oxus River. Shortughaï is located less than 20 km from that point. Harappans could have also left the Peshawar Valley by a northerly route, passed through the Swat and Chitral valleys (over the Malakand and Lowari passes respectively) and the took the Dorah pass eastward toward Badakhshan and the lapis lazuli mines. A variation on this route would have them exiting the Peshawar Valley from the east, following the Indus River north for a ways and entering the Swat Valley via the Shangla Pass. By doing so, they would have passed nearby the Sherwan steatite deposits in the Hazara region, which is where the large majority of steatite used at Harappa is now known to have been derived.

Indus Civilization peoples may have journeyed to Shortughaï by any or all of the routes described above. However, I would argue that the evidence presented here most favors those routes that first passed through either the Potwar Plateau / Peshawar Valley regions or the Gomal Plain.

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Post Script



Alexander Douglas Law

Gestation: 9 months
D.O.B.: 10 February, 2008
Weight: 7 lbs. 11 oz



This dissertation

Gestation: 10 years
D.O.B.: 8 May, 2008
Weight: 13 lbs